US009313509B2

(12) **United States Patent**
Lin et al.

(10) **Patent No.: US 9,313,509 B2**
(45) **Date of Patent: Apr. 12, 2016**

(54) **DC COEFFICIENT SIGNALING AT SMALL QUANTIZATION STEP SIZES**

(75) Inventors: **Chih-Lung Lin**, Redmond, WA (US); **Shankar Regunathan**, Bellevue, WA (US); **Sridhar Srinivasan**, Shanghai (CN)

(73) Assignee: **Microsoft Technology Licensing, LLC**, Redmond, WA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 448 days.

(21) Appl. No.: **12/815,029**

(22) Filed: **Jun. 14, 2010**

(65) **Prior Publication Data**

US 2010/0246671 A1 Sep. 30, 2010

Related U.S. Application Data

(60) Division of application No. 10/893,168, filed on Jul. 17, 2004, now Pat. No. 7,738,554, which is a continuation of application No. 10/623,195, filed on Jul. 18, 2003, now Pat. No. 7,602,851.

(60) Provisional application No. 60/488,710, filed on Jul. 18, 2003.

(51) **Int. Cl.**

H04N 7/12	(2006.01)
H04N 11/02	(2006.01)
H04N 11/04	(2006.01)

(Continued)

(52) **U.S. Cl.**

CPC ***H04N 19/17*** (2014.11); ***H04N 19/124*** (2014.11); ***H04N 19/126*** (2014.11); ***H04N 19/136*** (2014.11); ***H04N 19/137*** (2014.11); ***H04N 19/176*** (2014.11); ***H04N 19/18*** (2014.11); ***H04N 19/46*** (2014.11); ***H04N 19/61*** (2014.11); ***H04N 19/70*** (2014.11)

(58) **Field of Classification Search**

USPC 375/240.03, 240.18, 240.23

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,454,546	A	6/1984	Mori
4,583,114	A	4/1986	Catros

(Continued)

FOREIGN PATENT DOCUMENTS

CA	1327074	2/1994
EP	0 279 053	8/1988

(Continued)

OTHER PUBLICATIONS

U.S. Appl. No. 60/341,674, filed Dec. 17, 2001, Lee et al.

(Continued)

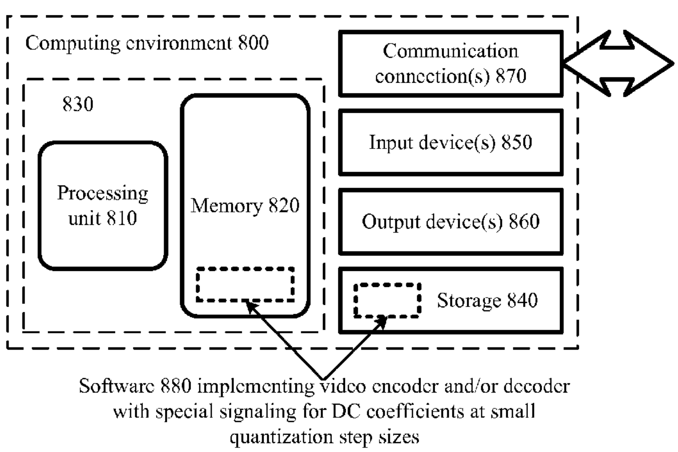
Primary Examiner — Chikaodili E Anyikire

(74) *Attorney, Agent, or Firm* — Sunah Lee; Judy Lee; Micky Minhas

(57) **ABSTRACT**

Described tools and techniques relate to signaling for DC coefficients at small quantization step sizes. The techniques and tools can be used in combination or independently. For example, a tool such as a video encoder or decoder processes a VLC that indicates a DC differential for a DC coefficient, a FLC that indicates a value refinement for the DC differential, and a third code that indicates the sign for the DC differential. Even with the small quantization step sizes, the tool uses a VLC table with DC differentials for DC coefficients above the small quantization step sizes. The FLCs for DC differentials have lengths that vary depending on quantization step size.

29 Claims, 12 Drawing Sheets



(51) **Int. Cl.**

H04N 19/17	(2014.01)
H04N 19/176	(2014.01)
H04N 19/70	(2014.01)
H04N 19/46	(2014.01)
H04N 19/61	(2014.01)
H04N 19/124	(2014.01)
H04N 19/126	(2014.01)
H04N 19/136	(2014.01)
H04N 19/137	(2014.01)
H04N 19/18	(2014.01)

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,661,849 A 4/1987 Hinman
4,661,853 A 4/1987 Roeder et al.
4,679,079 A 7/1987 Catros et al.
4,691,329 A 9/1987 Juri et al.
4,695,882 A 9/1987 Wada et al.
4,774,574 A 9/1988 Daly et al.
4,796,087 A 1/1989 Guichard et al.
4,800,432 A 1/1989 Barnett et al.
4,849,812 A 7/1989 Borgers et al.
4,862,264 A 8/1989 Wells et al.
4,862,267 A 8/1989 Gillard et al.
4,864,393 A 9/1989 Harradine et al.
4,965,830 A 10/1990 Barham et al.
4,992,889 A 2/1991 Yamagami et al.
5,021,879 A 6/1991 Vogel
5,068,724 A 11/1991 Krause et al.
5,072,295 A 12/1991 Murakami et al.
5,091,782 A 2/1992 Krause et al.
5,103,306 A 4/1992 Weiman et al.
5,128,758 A 7/1992 Azadegan et al.
5,136,377 A 8/1992 Johnston et al.
5,157,490 A 10/1992 Kawai et al.
5,175,618 A 12/1992 Ueda
5,179,442 A 1/1993 Azadegan et al.
5,223,949 A 6/1993 Honjo
5,237,410 A 8/1993 Inoue
5,241,395 A 8/1993 Chen
5,253,058 A 10/1993 Gharavi
5,258,836 A 11/1993 Murata
5,298,991 A 3/1994 Yagasaki et al.
5,301,242 A 4/1994 Gonzales et al.
5,303,058 A 4/1994 Fukuda et al.
5,317,396 A 5/1994 Fujinami
5,317,672 A 5/1994 Crossman et al.
5,374,958 A 12/1994 Yanagihara
5,412,430 A 5/1995 Nagata
RE34,965 E 6/1995 Sugiyama
5,422,676 A 6/1995 Herpel et al.
5,424,779 A 6/1995 Odaka
5,428,396 A 6/1995 Yagasaki
5,442,400 A 8/1995 Sun
5,448,297 A 9/1995 Alattar et al.
5,452,104 A 9/1995 Lee
5,461,421 A 10/1995 Moon
RE35,093 E 11/1995 Wang et al.
5,467,086 A 11/1995 Jeong
5,467,136 A 11/1995 Odaka
5,477,272 A 12/1995 Zhang
5,481,553 A 1/1996 Suzuki et al.
RE35,158 E 2/1996 Sugiyama
5,510,840 A 4/1996 Yonemitsu et al.
5,539,466 A 7/1996 Igarashi et al.
5,544,286 A 8/1996 Laney
5,552,832 A 9/1996 Astle
5,559,557 A 9/1996 Kato
5,565,920 A 10/1996 Lee et al.
5,565,922 A 10/1996 Krause
5,587,708 A 12/1996 Chiu
5,594,504 A 1/1997 Ebrahimi
5,606,371 A 2/1997 Gunnewick et al.
5,623,311 A 4/1997 Phillips et al.
5,623,424 A 4/1997 Azadegan et al.
5,631,644 A 5/1997 Katata et al.
5,654,760 A 8/1997 Ohtsuki
5,657,087 A 8/1997 Jeong et al.
5,659,365 A 8/1997 Wilkinson
5,663,763 A 9/1997 Yagasaki et al.
5,666,461 A 9/1997 Igarashi et al.
5,668,932 A 9/1997 Laney
5,673,370 A 9/1997 Laney
5,692,063 A 11/1997 Lee et al.
5,699,476 A 12/1997 Van Der Meer
5,701,164 A 12/1997 Kato
5,731,836 A 3/1998 Lee
5,731,837 A 3/1998 Hurst, Jr.
5,739,861 A 4/1998 Music
5,748,789 A 5/1998 Lee et al.
5,751,358 A 5/1998 Suzuki et al.
5,751,379 A 5/1998 Markandey et al.
5,761,088 A 6/1998 Hulyalkar et al.
5,764,803 A 6/1998 Jacquin et al.
5,764,814 A 6/1998 Chen et al.
5,784,175 A 7/1998 Lee
5,786,856 A 7/1998 Hall et al.
5,787,203 A 7/1998 Lee et al.
5,796,855 A 8/1998 Lee
5,799,113 A 8/1998 Lee
RE35,910 E 9/1998 Nagata et al.
5,802,213 A 9/1998 Gardos
5,809,178 A 9/1998 Anderson et al.
5,819,035 A 10/1998 Devaney et al.
5,825,310 A 10/1998 Tsutsui
5,825,929 A 10/1998 Chen et al.
5,835,145 A * 11/1998 Ouyang et al. 375/240.2
5,835,237 A 11/1998 Ebrahimi
5,844,613 A 12/1998 Chaddha
5,847,776 A 12/1998 Khmelnitsky
5,867,167 A 2/1999 Deering
5,870,435 A 2/1999 Choi et al.
5,874,995 A 2/1999 Naimpally et al.
5,883,672 A 3/1999 Suzuki et al.
5,901,248 A 5/1999 Fandrianto et al.
5,929,940 A 7/1999 Jeannin
5,946,042 A 8/1999 Kato
5,946,043 A 8/1999 Lee et al.
5,946,419 A 8/1999 Chen et al.
5,949,489 A 9/1999 Nishikawa et al.
5,959,673 A 9/1999 Lee et al.
5,963,258 A 10/1999 Nishikawa et al.
5,963,673 A 10/1999 Kodama et al.
5,969,764 A 10/1999 Sun et al.
5,970,173 A 10/1999 Lee et al.
5,970,175 A 10/1999 Nishikawa et al.
5,973,743 A 10/1999 Han
5,973,755 A 10/1999 Gabriel
5,974,184 A 10/1999 Eifrig et al.
5,982,437 A 11/1999 Okazaki et al.
5,982,438 A 11/1999 Lin et al.
5,990,957 A 11/1999 Ryoo
5,990,960 A 11/1999 Murakami et al.
5,991,447 A 11/1999 Eifrig et al.
6,002,439 A 12/1999 Murakami et al.
6,005,980 A 12/1999 Eifrig et al.
RE36,507 E 1/2000 Iu
6,011,596 A 1/2000 Burl
6,026,088 A * 2/2000 Rostoker et al. 370/395.53
6,026,195 A 2/2000 Eifrig et al.
6,040,863 A 3/2000 Kato
6,058,362 A 5/2000 Malvar
6,067,322 A 5/2000 Wang
6,072,831 A 6/2000 Chen
6,084,636 A 7/2000 Fujiwara
6,088,392 A 7/2000 Rosenberg
6,094,225 A 7/2000 Han
RE36,822 E 8/2000 Sugiyama
6,097,759 A 8/2000 Murakami et al.
6,104,751 A 8/2000 Artieri
6,118,817 A 9/2000 Wang
6,125,140 A 9/2000 Wilkinson

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,130,963 A 10/2000 Uz et al.
6,148,107 A 11/2000 Ducloux et al.
6,148,109 A * 11/2000 Boon et al. 382/238
6,154,495 A 11/2000 Yamaguchi et al.
6,160,846 A 12/2000 Chiang et al.
6,167,091 A 12/2000 Okada et al.
6,182,034 B1 1/2001 Malvar
6,188,725 B1 2/2001 Sugiyama
6,188,794 B1 2/2001 Nishikawa et al.
6,201,927 B1 3/2001 Comer
6,205,176 B1 3/2001 Sugiyama
6,208,761 B1 3/2001 Passagio et al.
6,212,232 B1 4/2001 Reed et al.
6,219,070 B1 4/2001 Baker et al.
6,219,464 B1 4/2001 Greggain et al.
6,223,162 B1 4/2001 Chen et al.
6,233,017 B1 5/2001 Chaddha
6,240,380 B1 5/2001 Malvar
RE37,222 E 6/2001 Yonemitsu
6,243,418 B1 6/2001 Kim
6,243,497 B1 6/2001 Chiang et al.
6,249,614 B1 6/2001 Bocharova et al.
6,256,422 B1 7/2001 Mitchell et al.
6,256,423 B1 7/2001 Krishnamurthy
6,259,810 B1 7/2001 Gill et al.
6,263,024 B1 7/2001 Matsumoto
6,271,885 B2 8/2001 Sugiyama
6,275,531 B1 8/2001 Li
6,275,614 B1 8/2001 Krishnamurthy et al.
6,278,735 B1 8/2001 Mohsenian
6,281,942 B1 8/2001 Wang
6,282,243 B1 8/2001 Kazui et al.
6,292,585 B1 9/2001 Yamaguchi et al.
6,292,588 B1 9/2001 Shen et al.
6,295,376 B1 9/2001 Nakaya
6,304,928 B1 10/2001 Mairs et al.
6,307,887 B1 10/2001 Gabriel
6,307,973 B2 10/2001 Nishikawa et al.
6,320,593 B1 11/2001 Sachs et al.
6,324,216 B1 11/2001 Igarashi
6,337,881 B1 1/2002 Chaddha
6,347,116 B1 * 2/2002 Haskell et al. 375/240.03
6,356,709 B1 3/2002 Abe et al.
6,370,502 B1 4/2002 Wu et al.
6,377,628 B1 4/2002 Schultz et al.
6,381,279 B1 4/2002 Taubman
6,393,155 B1 5/2002 Bright et al.
6,404,813 B1 6/2002 Haskell et al.
6,418,166 B1 7/2002 Wu et al.
6,430,316 B1 8/2002 Wilkinson
6,438,167 B1 8/2002 Shimizu et al.
6,441,842 B1 8/2002 Fandrianto et al.
6,456,744 B1 9/2002 Lafe
6,473,534 B1 10/2002 Merhav et al.
6,490,319 B1 12/2002 Yang
6,493,385 B1 12/2002 Sekiguchi et al.
6,496,601 B1 12/2002 Migdal et al.
6,519,284 B1 2/2003 Pesquet-Popescu et al.
6,529,632 B1 3/2003 Nakaya et al.
6,539,056 B1 3/2003 Sato et al.
6,546,049 B1 4/2003 Lee
6,563,953 B2 5/2003 Lin et al.
6,571,019 B1 * 5/2003 Kim et al. 382/246
6,573,905 B1 6/2003 MacInnis et al.
6,593,925 B1 7/2003 Hakura et al.
6,647,061 B1 11/2003 Panusopone et al.
6,647,152 B2 11/2003 Willis et al.
6,650,781 B2 11/2003 Nakaya
6,654,417 B1 11/2003 Hui
6,678,422 B1 1/2004 Sharma et al.
6,687,294 B2 2/2004 Yan et al.
6,704,718 B2 3/2004 Burges et al.
6,721,359 B1 4/2004 Bist et al.
6,728,317 B1 4/2004 Demos
6,738,423 B1 5/2004 Lainema et al.
6,759,999 B1 7/2004 Doyen
6,765,962 B1 7/2004 Lee et al.
6,771,830 B2 8/2004 Goldstein et al.
6,785,331 B1 8/2004 Jozawa et al.
6,792,157 B1 9/2004 Koshi et al.
6,795,584 B2 9/2004 Karczewicz et al.
6,801,572 B2 10/2004 Yamada et al.
6,810,083 B2 10/2004 Chen et al.
6,831,947 B2 12/2004 Ribas Corbera
6,873,654 B1 3/2005 Rackett
6,876,703 B2 4/2005 Ismaeil et al.
6,882,753 B2 4/2005 Chen et al.
6,947,045 B1 9/2005 Ostermann et al.
6,970,479 B2 11/2005 Abrahamsson et al.
6,990,242 B2 1/2006 Malvar
7,020,204 B2 3/2006 Auvray et al.
7,027,507 B2 4/2006 Wu
7,035,473 B1 4/2006 Zeng et al.
7,042,941 B1 5/2006 Laksono et al.
7,058,127 B2 6/2006 Lu et al.
7,099,389 B1 8/2006 Yu et al.
7,110,455 B2 9/2006 Wu et al.
2001/0048718 A1 12/2001 Bruls et al.
2002/0044602 A1 4/2002 Ohki
2002/0136308 A1 9/2002 Le Maguet et al.
2002/0154693 A1 10/2002 Demos et al.
2002/0168066 A1 11/2002 Li
2002/0186890 A1 12/2002 Lee et al.
2003/0009722 A1 * 1/2003 Sugiyama et al. 714/779
2003/0021482 A1 1/2003 Lan et al.
2003/0099292 A1 5/2003 Wang et al.
2003/0112864 A1 6/2003 Karczewicz et al.
2003/0113026 A1 6/2003 Srinivasan et al.
2003/0128754 A1 7/2003 Akimoto et al.
2003/0142748 A1 7/2003 Tourapis
2003/0152146 A1 8/2003 Lin et al.
2003/0156646 A1 8/2003 Hsu et al.
2003/0194010 A1 10/2003 Srinivasan et al.
2003/0215011 A1 11/2003 Wang et al.
2004/0022316 A1 2/2004 Ueda et al.
2004/0042549 A1 3/2004 Huang et al.
2004/0090397 A1 5/2004 Doyen et al.
2004/0136457 A1 7/2004 Funnell et al.
2004/0141654 A1 7/2004 Jeng
2004/0264568 A1 12/2004 Florencio
2004/0264580 A1 12/2004 Chiang Wei Yin et al.
2005/0013365 A1 1/2005 Mukerjee et al.
2005/0013497 A1 1/2005 Hsu et al.
2005/0013498 A1 1/2005 Srinivasan et al.
2005/0013500 A1 1/2005 Lee et al.
2005/0015246 A1 1/2005 Thumpudi et al.
2005/0015259 A1 1/2005 Thumpudi et al.
2005/0036698 A1 2/2005 Beom
2005/0036699 A1 2/2005 Holcomb et al.
2005/0036759 A1 2/2005 Lin et al.
2005/0041738 A1 2/2005 Lin et al.
2005/0052294 A1 3/2005 Liang et al.
2005/0053156 A1 3/2005 Lin et al.
2005/0094731 A1 5/2005 Xu et al.
2005/0100093 A1 5/2005 Holcomb
2005/0123274 A1 6/2005 Crinon et al.
2005/0135484 A1 6/2005 Lee et al.
2005/0147163 A1 7/2005 Li et al.
2005/0152451 A1 7/2005 Byun
2005/0180502 A1 8/2005 Puri
2005/0207492 A1 9/2005 Pao
2005/0232501 A1 10/2005 Mukerjee
2005/0254719 A1 11/2005 Sullivan
2006/0013307 A1 1/2006 Olivier et al.
2006/0013309 A1 1/2006 Ha et al.
2006/0140267 A1 6/2006 He et al.
2007/0009039 A1 1/2007 Ryu
2007/0009042 A1 1/2007 Craig et al.
2010/0080297 A1 4/2010 Wang et al.

FOREIGN PATENT DOCUMENTS

EP 0397402 11/1990
EP 0526163 2/1993

(56) **References Cited**

FOREIGN PATENT DOCUMENTS

EP	0535746	4/1993
EP	0 083 029	3/1998
EP	0863675	9/1998
EP	0884912	12/1998
EP	0932306	7/1999
GB	897363	5/1962
GB	2343579	5/2000
JP	61205086	9/1986
JP	62 213 494	9/1987
JP	3001688	1/1991
JP	3 129 986	3/1991
JP	6 078 298	3/1994
JP	6078295	3/1994
JP	7274171	10/1995
JP	10 056 644	2/1998
JP	2003061090	2/2003
JP	6292188	10/2004
KR	132895	10/1998
KR	1020020005365	1/2002
WO	WO 97/21302	6/1997
WO	WO 00/21207	4/2000
WO	WO 00/33581	8/2000
WO	WO 02/07438	1/2002
WO	WO 03/026296	3/2003
WO	WO 2004/100554	11/2004
WO	WO 2004/100556	11/2004
WO	WO 2005/065030	7/2005
WO	WO 2006/075895	7/2006

OTHER PUBLICATIONS

U.S. Appl. No. 60/488,710, filed Jul. 18, 2003, Srinivasan et al.

Ahmed et al., "Discrete Cosine Transform," *IEEE Trans. On Computers*, vol. C-23, No. 1, pp. 90-93 (Dec. 1984).

Atzori et al., "Adaptive Anisotropic Filtering (AAF) for Real-Time Visual Enhancement of MPEG-Coded Video Sequences," *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 12, No. 5, pp. 285-298 (May 2002).

Bartkowiak et al., "Color Video Compression Based on Chrominance Vector Quantization," 7th Int'l Workshop on Systems, Signals and Image Processing, IWSSIP 2000, Maribor 7-9 VI, pp. 107-110 (2000).

Bist et al., "Adaptive Quantization for Low Bit Rate Video Coding," *Proc. 1998 Int'l Conf. on Image Processing* (*ICIP* 98), pp. 925-928 (1998).

Borman et al., "Block-matching Sub-pixel Motion Estimation from Noisy, Under-Sampled Frames—an Empirical Performance Evaluation," *SPIE Visual Comm. & Image Processing*, 10 pp. (1999).

Chisu, "Techniques for Accelerating Intensity-Based Rigid Image Registration," Thesis dated Jan. 15, 2005.

Clarke, "Image and Video Compression: A Survey," *Wiley InterScience Journal Abstract*, 2 pp., http://www.3.interscience.wiley.com [Downloaded from the World Wide Web on Jan. 25, 2006].

Conklin et al., "Multi-resolution Motion Estimation," Proc. ICASSP '97, Munich, Germany, 4 pp. (1997).

Davis et al., "Equivalence of subpixel motion estimators based on optical flow and block matching," Proc. IEEE Int'l Symposium on Computer Vision, pp. 7-12 (1995).

de Haan et al., "Sub-pixel motion estimation with 3-D recursive search block-matching," Signal Processing: Image Comm. 6, pp. 229-239 (1994).

"DivX Multi Standard Video Encoder," 2 pp. (Downloaded from the World Wide Web on Jan. 24, 2006).

Ebrahimi, "MPEG-4 Video Verification Model Version 10.0," ISO/IEC JTC1/SC29/WG11, MPEG98/N1992, pp. 1, 43-52, 72-74, 123-130, and 190, document marked 1998.

Ericsson, "Fixed and Adaptive Predictors for Hybrid Predictive/Transform Coding," IEEE Transactions on Comm., vol. COM-33, No. 12, pp. 1291-1302 (1985).

Farvardin et al., "Optimum quantizer performance for a class of non-Gaussian memoryless sources," *IEEE Trans. Inform. Theory*, vol. IT-30, No. 3, pp. 485-497 (May 1984).

"A Fast Precise Implementation of 8×8 Discrete Cosine Transform Using the Streaming SIMD Extensions and MMX™ Instructions," Version 1.0, 25 pp. (Apr. 1999).

Flierl et al., "A Video Codec Incorporating Block-Based Multi-Hypothesis Motion-Compensated Prediction," in *Proceedings of the SPIE Conference on Visual Communications and image Processing*, Perth, Australia, vol. 4067, pp. 238-249 (Jun. 2000).

Flierl et al., "Generalized B Pictures and the Draft H.264/AVC Video Compression Standard," in *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 13, No. 7, pp. 587-597 (Jul. 2003).

Flierl et al., "Multihypothesis Motion Estimation for Video Coding," Proc. DCC, 10 pp. (Mar. 2001).

Foos et al., "JPEG 2000 compression of medical imagery," *Proc. SPIE*, vol. 3980, pp. 85-96 (2000).

Garrigues et al., "Atom position coding in a matching pursuit based video coder," *Lecture Notes in Computer Science*, 4 pp. (2005).

Girod, "Efficiency Analysis of Multihypothesis Motion-Compensated Prediction for Video Coding," *IEEE Transactions on Image Processing*, vol. 9, No. 2, pp. 173-183 (Feb. 2000).

Girod, "Motion-Compensating Prediction with Fractional-Pel Accuracy," *IEEE Transactions on Comm.*, vol. 41, No. 4, pp. 604-612 (1993).

Girod, "Motion Compensation: Visual Aspects, Accuracy, and Fundamental Limits," Motion Analysis and Image Sequence Processing, Kluwer Academic Publishers, pp. 125-152 (1993).

Gish et al., "Asymptotically efficient quantizing," *IEEE Trans. Inform. Theory*, vol. IT-14, No. 5 (Sep. 1968).

Golston et al., "Video codecs tutorial: Trade-offs with H.264, VC-1 and other advanced codecs," *Video/Imaging Design Line*, 9 pp. (Mar. 2006).

"H.264 & IPTV Over DSL—Enabling New Telco Revenue Opportunities," *White Paper*, Intel/Envivio, May 15, 2004, available at http://www.envivio.com/images/products/H264whitepaper.pdf.

Horn et al., "Estimation of Motion Vector Fields for Multiscale Motion Compensation," *Proc. Picture Coding Symp.* (PCS 97), pp. 141-144 (Sep. 1997).

Hsu et al., "A Low Bit-Rate Video Codec Based on Two-Dimensional Mesh Motion Compensation with Adaptive Interpolation," *IEEE, Transactions on Circuits and Systems for Video Technology*, vol. II, No. 1, pp. 111-117 (Jan. 2001).

Huang et al., "A Frame-Based MPEG Characteristics Extraction Tool and its Application in Video Transcoding," IEEE Transactions on Consumer Electronics, vol. 48, No. 3, Aug. 2002, pp. 522-532.

"ISO/IEC 11172-2 Coding of moving pictures and associated audio for digital storage media at up to about 1.5 Mbit/s," MPEG (Moving Pictures Expert Group), International Organization for Standardization, MPEG1 Video, 122 pp. (1993).

"ISO/IEC 13818-2. Generic coding of moving pictures and associated audio information," MPEG (Moving Pictures Expert Group), International Organization for Standardization, MPEG2 Video (1994).

ISO/IEC, "Information Technology—Coding of Audio-Visual Objects: Visual, ISO/IEC 14496-2, Committee Draft," 330 pp. (1998).

ISO/IEC, "Coding of Moving Pictures and Associated Audio Information," JTCI/SC29/WG11, MPEG-4 Video Verification Model (Feb. 1998).

"ITU-T Recommendation T.6: Facsimile Coding Schemes and Coding Control Functions for Group 4 Facsimile Apparatus," Facicle VII.3 of the Blue Book, (1988).

ITU—Q15-F-24, "MVC Video Codec—Proposal for H.26L," Study Group 16, Video Coding Experts Group (Question 15), 28 pp. (document marked as generated in 1998).

ITU-T, "ITU-T Recommendation H.261: Video Codec for Audiovisual Services at p×64 kbits," 28 pp. (1993).

ITU-T, "ITU-T Recommendation H.262: Information Technology—Generic Coding of Moving Pictures and Associated Audio Information: Video," 218 pp. (1995).

ITU-T, "ITU-T Recommendation H.263: Video Coding for Low Bit Rate Communication," 167 pp. (1998).

Iwahashi et al., "A Motion Compensation Technique for Downscaled Pictures in Layered Coding," *IEICE Transactions on Comm.*, vol. E77-B, No. 8, pp. 1007-1012 (Aug. 1994).

(56) **References Cited**

OTHER PUBLICATIONS

Joint Video Team (JVT) of ISO/IEC MPEG & ITU-T VCEG, "Draft ITU-T Recommendation and Final Draft International Standard of Joint Video Specification (ITU-T Rec. H.264 ISO/IEC 14496-10 AVC," 253 pp. (May 2003).
Joint Video Team of ISO/IEC MPEG and ITU-T VCEG, "Committee Draft of Joint Video Specification (ITU-T Recommendation H.264, ISO/IEC 14496-10 AVC," 142 pp. (Aug. 2002).
Joshi et al., "Comparison of generalized Gaussian and Laplacian modeling in DCT image coding," *IEEE Signal Proc. Letters*, vol. SPL-2, No. 5, pp. 81-82 (May 1995).
Keys, "Cubic Convolution Interpolation for Digital Image Processing," *IEEE Transactions on Acoustics, Speech & Signal Processing*, vol. ASSP-29, No. 6, pp. 1153-1160 (1981).
Kim et al., "Still image coding based on vector quantization and fractal approximation," *IEEE Transactions on Image Processing*, vol. 5, No. 4, pp. 587-597 (1996).
Konrad et al., "On Motion Modeling and Estimation for Very Low Bit Rate Video Coding," *Visual Comm. & Image Processing* (VCIP '95), 12 pp. (May 1995).
Lam et al., "A mathematical analysis of the DCT coefficient distributions for images," *IEEE Trans. Image Proc.*, vol. IP-9, No. 10, pp. 1661-1666 (Oct. 2000).
LeGall, "MPEG: A Video Compression Standard for Multimedia Application," *Communications of the ACM*, vol. 34, No. 4, pp. 47-58 (Apr. 1991).
LeGall, "The MPEG Video Compression Algorithm," *Signal Processing: Image Communication 4*, vol. 4, No. 2, pp. 129-140 (Apr. 1992).
LeGall et al., "Transmission of HDTV signals under 140 Mbit/s using a subband decomposition and Discrete Cosine Transform coding," in *Signal Processing of HDTV*, Elsevier, Amsterdam, pp. 287-293 (1988).
Limb, "A Picture-Coding Algorithm for the Merli Scan," *IEEE Transactions on Communications*, pp. 300-305 (Apr. 1973).
Lloyd, "Least squares quantization in PCM," *IEEE Trans. Inform. Theory*, vol. IT-28, No. 2, pp. 7-12 (Mar. 1982) (reprint of work originally presented in Jul. 1957).
Loomis, "Using the Advanced Settings of the Windows Media Video 9 Advanced Profile Codec," 13 pp. (Document dated Apr. 2006) [Downloaded from the World Wide Web on May 31, 2007].
Lopes et al., "Analysis of Spatial Transform Motion Estimation with Overlapped Compensation and Fractional-pixel Accuracy," *IEEE Proc. Visual Image Signal Processing*, vol. 146, No. 6, pp. 339-334 (Dec. 1999).
Lopresto et al., "Image Coding Based on Mixture Modeling of Wavelet Coefficients and a Fast Estimation-Quantization Framework," *Proc. IEEE Data Compression Conference*, (Snowbird, UT), pp. 221-230 (Mar. 1997).
Mallat, "A theory for multiresolution signal decomposition: the wavelet representation," *IEEE Trans. Pattern Anal. and Machine Intell.*, vol. PAMI-11, No. 7, pp. 674-692 (Jul. 1989).
Marshall, "The Discrete Cosine Transform," 4 pp. (document dated Oct. 4, 2001) [downloaded from the World Wide Web on Mar. 30, 2006].
Martinez-Fonte et al., "An Empirical Study on Corner Detection to Extract Buildings in Very High Resolution Satellite Images," *IEEE-ProRisc*, Veldhoven, The Netherlands, pp. 288-293 (Nov. 2004).
Masala et al., "Perceptually Optimized MPEG Compression of Synthetic Video Sequences," *Proc. ICIP*, pp. I-601-I-604 (2005).
Max, "Quantizing for minimum distortion," *IEEE Trans. Inform. Theory*, vol. IT-6, No. 1, pp. 7-12 (Mar. 1960).
Microsoft Corporation, "Microsoft Debuts New Windows Media Player 9 Series, Redefining Digital Media on the PC," 4 pp. (Sep. 4, 2002) [Downloaded from the World Wide Web on May 14, 2004].
Mitra et al., "Two-Stage Color Palettization for Error Diffusion," *Proceedings of SPIE*, pp. 207-217 (Jun. 2002).
Mook, "Next-Gen Windows Media Player Leaks to the Web," *BetaNews*, 17 pp. (Jul. 19, 2002) [Downloaded from the World Wide Web on Aug. 8, 2003].
Morimoto et al., "Fast Electronic Digital Image Stabilization," *Proc. ICPR*, Vienna, Austria, 5 pp. (1996).
Muller, "Distribution shape of two-dimensional DCT coefficients of natural images," *IEE Electronics Letters*, vol. 29, No. 22 (Oct. 1993).
Murakami et al., "Comparison between DPCM and Hadamard transform coding in the composite coding of the NTSC color TV signal," *IEEE Trans. On Commun.*, vol. COM-30, No. 3, pp. 469-479 (Mar. 1982).
Musmann et al., "Advances in Picture Coding," *Proceedings of the IEEE*, vol. 73, No. 4, pp. 523-548 (Apr. 1985).
Neff et al., "Modulus Quantization for Matching Pursuit Video Coding," *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 10, No. 6, pp. 895-912 (Sep. 2000).
Nguyen et al., "Set Theoretic Compression with an Application to Image Coding," *IEEE Transactions on Image Processing*, vol. 7, No. 7, pp. 1051-1056 (Jul. 1998).
Nougaret et al., "Quick Tuning of a Reference Locomotion Gait," *IEEE Proc. Computer Animation* '95, 8 pp. (1995).
"Overview of MPEG-2 Test Model 5," 5 pp. [Downloaded from the World Wide Web on Mar. 1, 2006].
Park et al., "A post processing method for reducing quantization effects in low bit-rate moving picture coding," *IEEE Trans. Circuits Syst. Video Technology*, vol. 9, pp. 161-171 (Feb. 1999).
Printouts of FTP directories from http://ftp3.itu.ch , 8 pp. (downloaded from the World Wide Web on Sep. 20, 2005.).
Puri et al., "Motion-Compensated Video Coding with Adaptive Perceptual Quantization," *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 1, No. 4, pp. 351-361 (Dec. 1991).
Reader, "History of MPEG Video Compression—Ver. 4.0," 99 pp., (document marked Dec. 16, 2003).
Reininger et al., "Distribution of two-dimensional DCT coefficients for images," *IEEE Trans. On Commun.*, vol. COM-31, No. 6, pp. 835-839 (Jun. 1983).
Ribas-Corbera et al., "On the Optimal Block Size for Block-based Motion-Compensated Video Coders," *SPIE Proc. of Visual Comm. & Image Processing*, vol. 3024, 12 pp. (1997).
Ribas-Corbera et al., "On the Optimal Motion Vector Accuracy for Block-based Motion-Compensated Video Coders," *Proc. SPIE Digital Video Compression*, San Jose, CA, 13 pp. (1996).
Ribas Corbera et al., "Rate Control in DCT Video Coding for Low-Delay Communications," *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 9, No. 1, pp. 178-185 (Feb. 1999).
Schultz et al., "Subpixel Motion Estimation for Super-Resolution Image Sequence Enhancement," *Journal of Visual Comm. & Image Representation*, vol. 9, No. 1, pp. 38-50 (Mar. 1998).
Schuster et al., "A Theory for the Optimal Bit Allocation Between Displacement Vector Field and Displaced Frame Difference," *IEEE J. on Selected Areas in Comm.*, vol. 15, No. 9, pp. 1739-1751 (Dec. 1997).
Shanableh et al., "Heterogeneous Video Transcoding to Lower Spatio-Temporal Resolutions and Different Encoding Formats," *IEEE Transactions on Multimedia*, vol. 2, No. 2, pp. 101-110 (Jun. 2000).
Shen et al., "Rate-Distortion Optimization for Fast Hierarchical B-Picture Transcoding," *IEEE*, pp. 5279-5282 (2006).
Shoushun et al., "Adaptive-Quantization Digital Image Sensor for Low-Power Image Compression," in *IEEE Transactions on Circuits and Systems—I: Regular Papers*, vol. 54, No. 1, pp. 13-25 (Jan. 2007).
Sjoberg et al., "Run-length Coding of Skipped Macroblocks," ITU-T SG16/Q.6 VCEG-M57, pp. 1-5 (Apr. 2001).
Sony Electronics Inc., "Sony Vizaro DVD Encoder System DVA-V700," 4 pp. (2001).
Sullivan, "Efficient scalar quantization of exponential and Laplacian random variables," *IEEE Trans. Inform. Theory*, vol. IT-42, No. 5, pp. 1365-1374 (Sep. 1996).
Sullivan et al., "Rate-Distortion Optimization for Video Compression," *IEEE Signal Processing Magazine*, pp. 74-90 (Nov. 1998).
Sullivan et al., "The H.264/AVC Advanced V ideo Coding Standard: Overview and Introduction to the Fidelity Range Extensions," 21 pp. (Aug. 2004).

(56) **References Cited**

OTHER PUBLICATIONS

Tao et al., "Adaptive Model-driven Bit Allocation for MPEG Video Coding," *IEEE Transactions on Circuits and Systems for Video Tech.*, vol. 10, No. 1, pp. 147-157 (Feb. 2000).
Tescher, "Transform image coding," *Advances in Electronics and Electron. Physics*, Suppl. 12, Academic Press, New York, pp. 113-115 (1979).
"The TML Project WEB-Page and Archive" (including pages of code marked "image.cpp for H.26L decoder, Copyright 1999" and "image.c"), 24 pp. [Downloaded from the World Wide Web on Jun. 1, 2005].
Triggs, "Empirical Filter Estimation for Subpixel Interpolation and Matching," *Int'l Conf. Computer Vision* '01, Vancouver, Canada, 8 pp. (Jul. 2001).
Triggs, "Optimal Filters for Subpixel Interpolation and Matching," *Int'l Conf. Computer Vision* '01, Vancouver, Canada, 10 pp. (Jul. 2001).
Tsang et al., "Fuzzy Based Rate Control for Real-Time MPEG Video," *IEEE Transactions on Fuzzy Systems*, pp. 504-516 (1998).
"Video Coding for Low Bitrate Communication," ITU-T Recommendation H.263 (1996).
"Video Coding Using Wavelet Decomposition for Very Low Bit-rate Networks," 16 pp. (1997).
Wang et al., "Interlace Coding Tools for H.26L Video Coding," ITU-T SG16/Q.6 VCEG-O37, pp. 1-20 (Dec. 2001).
Weiss et al., "Real Time Implementation of Subpixel Motion Estimation for Broadcast Applications," pp. 7/1-7/3 (1990).
Wien, "Variable Block-Size Transforms for Hybrid Video Coding," Dissertation, 182 pp. (Feb. 2004).
Wu et al., "Context-based adaptive lossless codec," *IEEE Trans. Communications*, vol. 45, pp. 437-444 (1997).
Wu et al., "Joint Estimation of Forward and Backward Motion Vectors for Interpolative Prediction of Video," *IEEE Transactions on Image Processing*, vol. 3, No. 5, pp. 684-687 (Sep. 1994).
Yang et al., "Rate Control for Videophone Using Local Perceptual Cues," *IEEE Transactions on Circuits and Systems for Video Tech.*, vol. 15, No. 4, pp. 496-507 (Apr. 2005).
Yang et al., "Very High Efficiency VLSI Chip-pair for Full Search Block Matching with Fractional Precision," *Proc. ICASSP/IEEE Int'l Conf. on Accoustics, Speech & Signal Processing*, Glasgow, pp. 2437-2440 (May 1989).
Yu et al., "Two-Dimensional Motion Vector Coding for Low Bitrate Videophone Applications," *Proc. Int'l Conf. on Image Processing*, Los Alamitos, US, pp. 414-417 (1995).
Yuen et al., "A survey of hybrid MC/DPCM/DCT video coding distortions," *Signal Processing*, vol. 70, pp. 247-278 (1998).
Zhang et al., "Adaptive Field/Frame Selection for High Compression Coding," *SPIE Conf. on Image and Video Communications and Processing*, 13 pp. (Jan. 2003).
AVC-0323, Test Model Editing Committee, "Test Model 2, Draft Revision 1," MPEG92/N0245, 171 pp. (1992).
Benzler et al., "Improving multiresolution motion compensating hybrid coding by drift reduction," Picture Coding Symposium, 4 pp. (1996).
Benzler et al., "Motion and aliasing compensating prediction with quarter-pel accuracy and adaptive overlapping blocks as proposal for MPEG-4 tool evaluation—Technical description," ISO/IEC JTC1/SC29/WG11, MPEG 95/0552, 5 pp., document marked 1995.
Benzler, "Results of core experiment P8 (Motion an Aliasing compensating Prediction)," ISO/IEC JTC1/SC29/WG11, MPEG97/2625, 8 pp., document marked 1997.

* cited by examiner

Figure 1, Prior Art

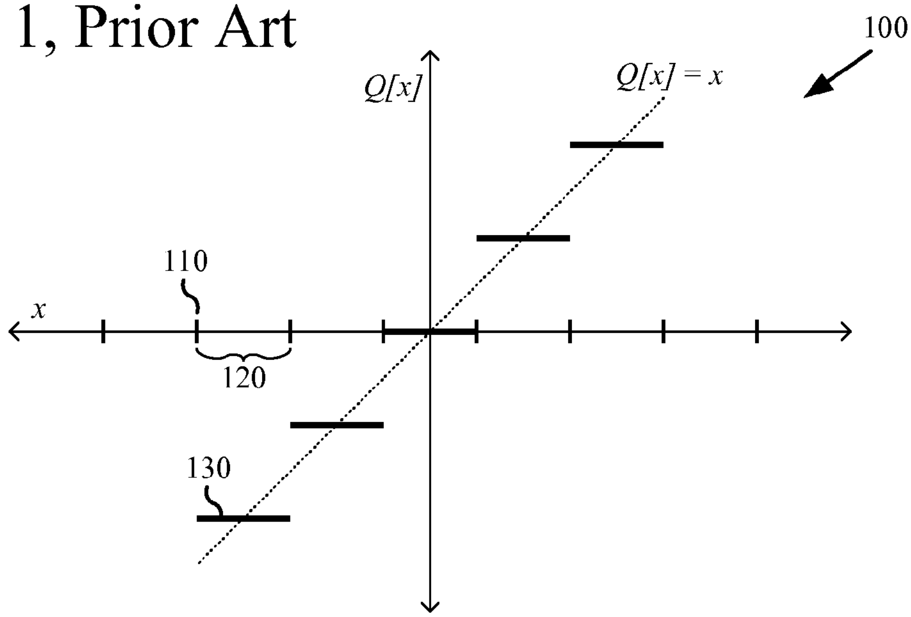


Figure 2a, Prior Art

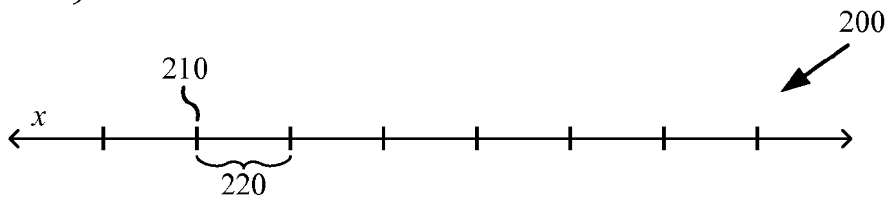


Figure 2b, Prior Art

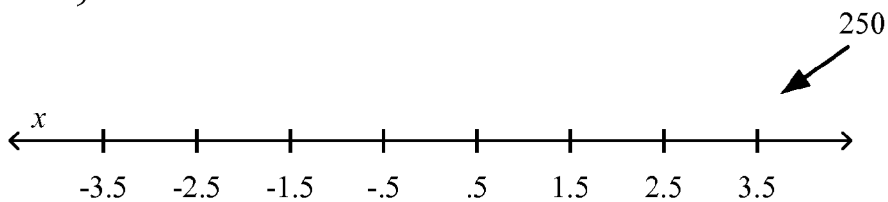


Figure 3, Prior Art

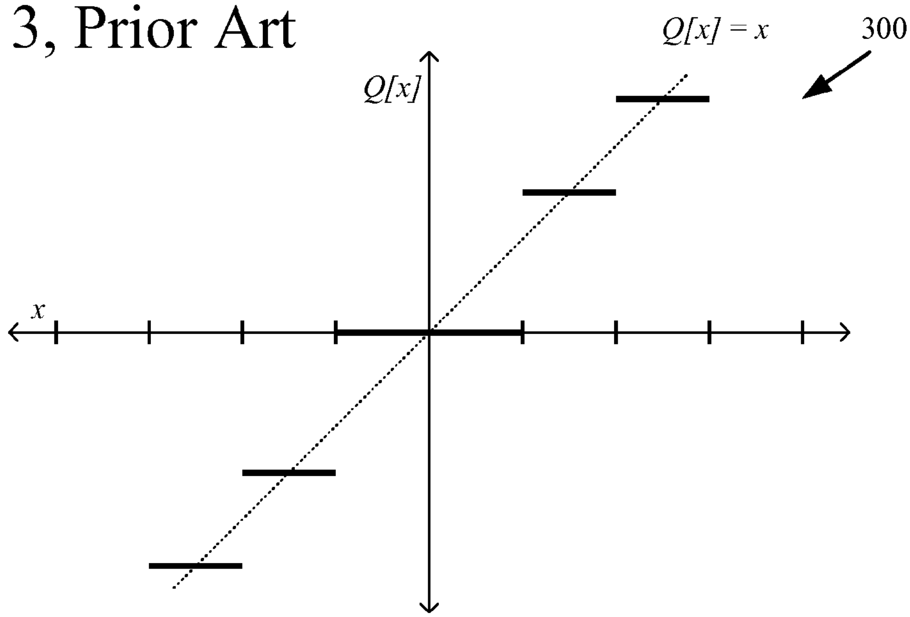


Figure 4a, Prior Art

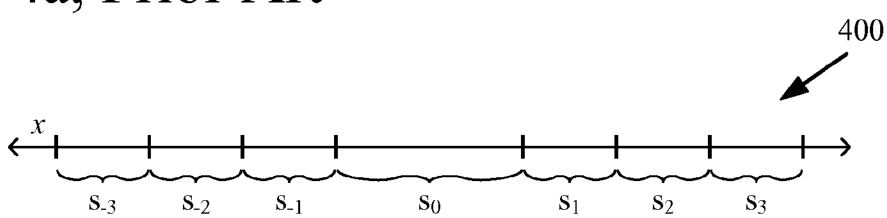


Figure 4b, Prior Art

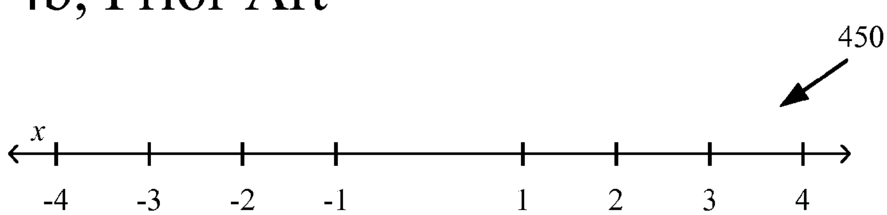


Figure 5, Prior Art

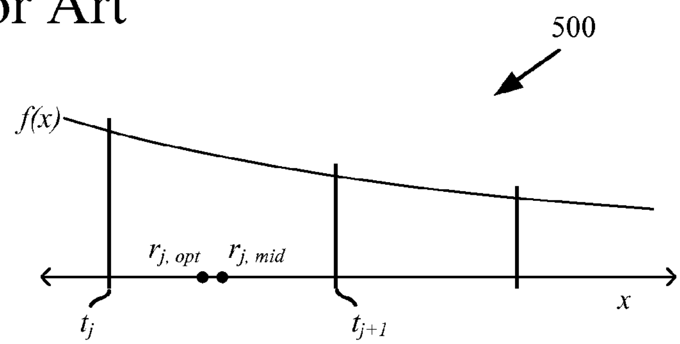


Figure 6, Prior Art

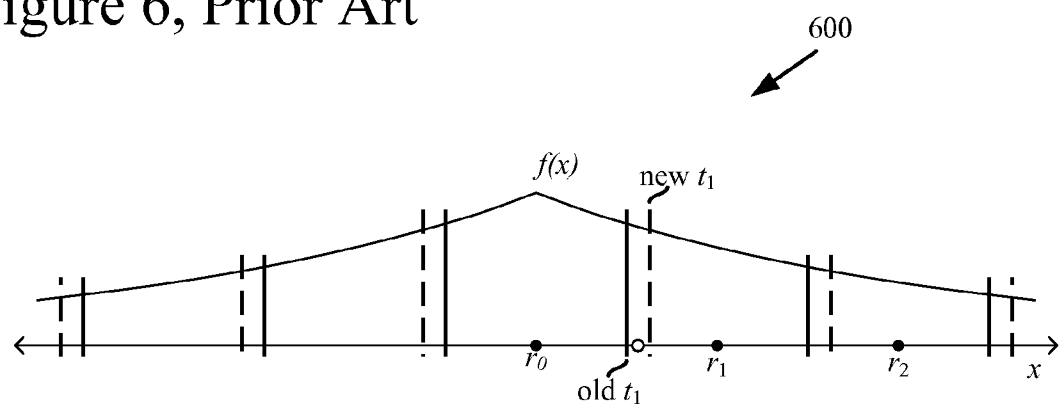


Figure 7, Prior Art

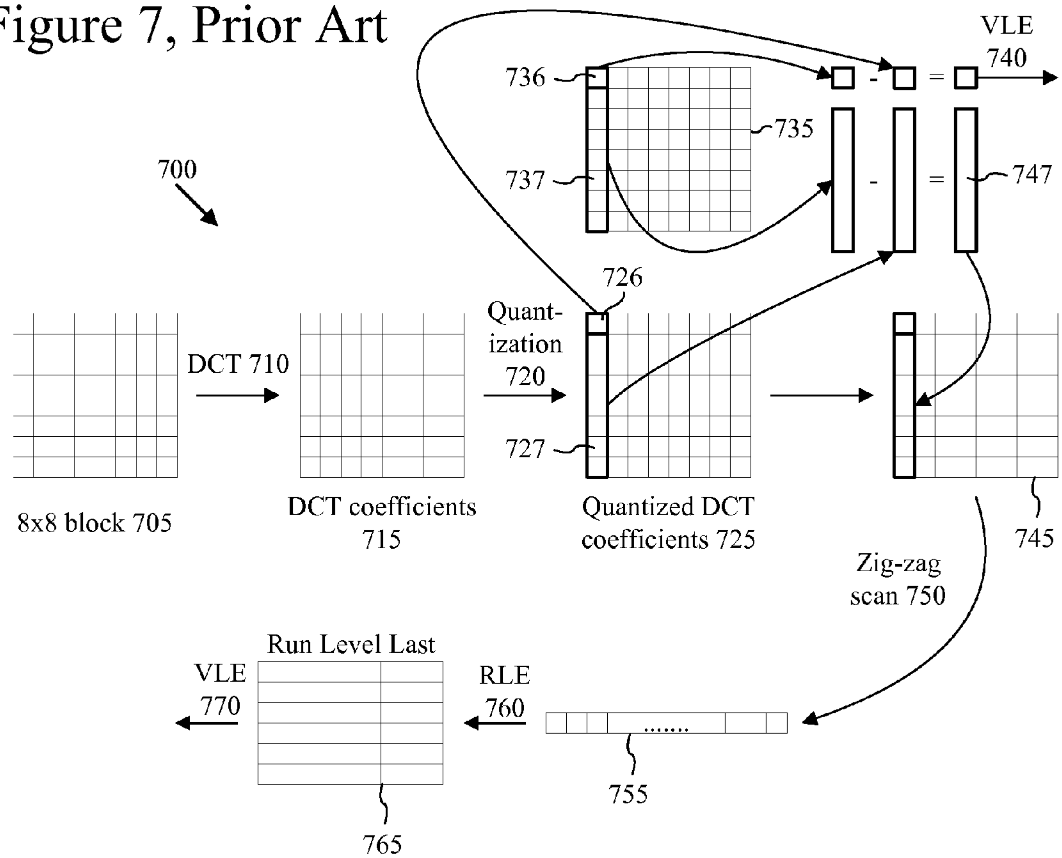


Figure 8

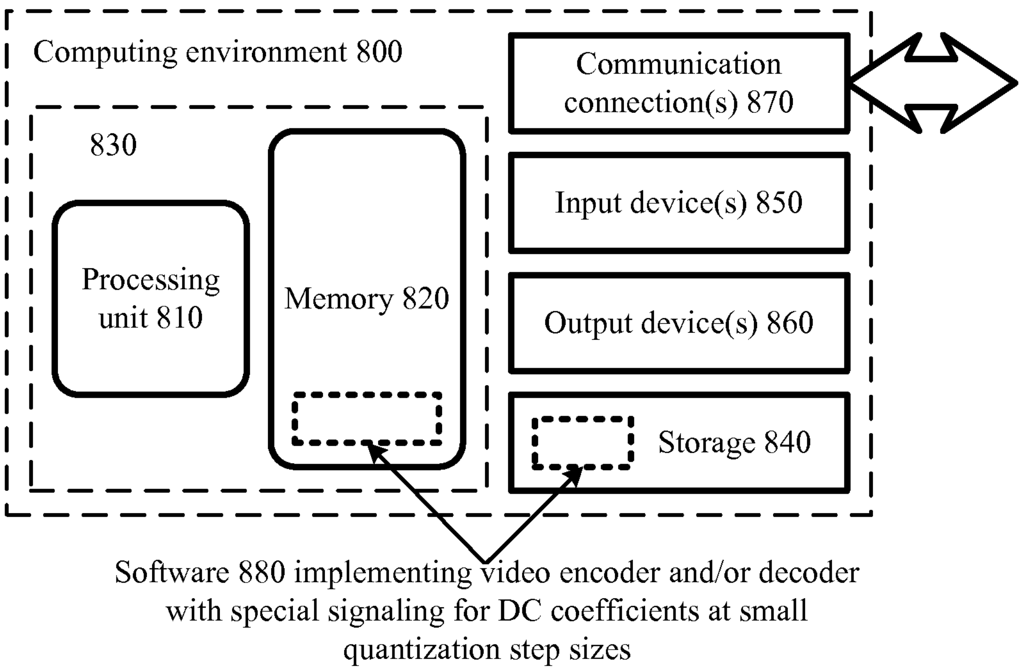

Computing environment 800
830
Processing unit 810
Memory 820
Communication connection(s) 870
Input device(s) 850
Output device(s) 860
Storage 840
Software 880 implementing video encoder and/or decoder with special signaling for DC coefficients at small quantization step sizes

Figure 9

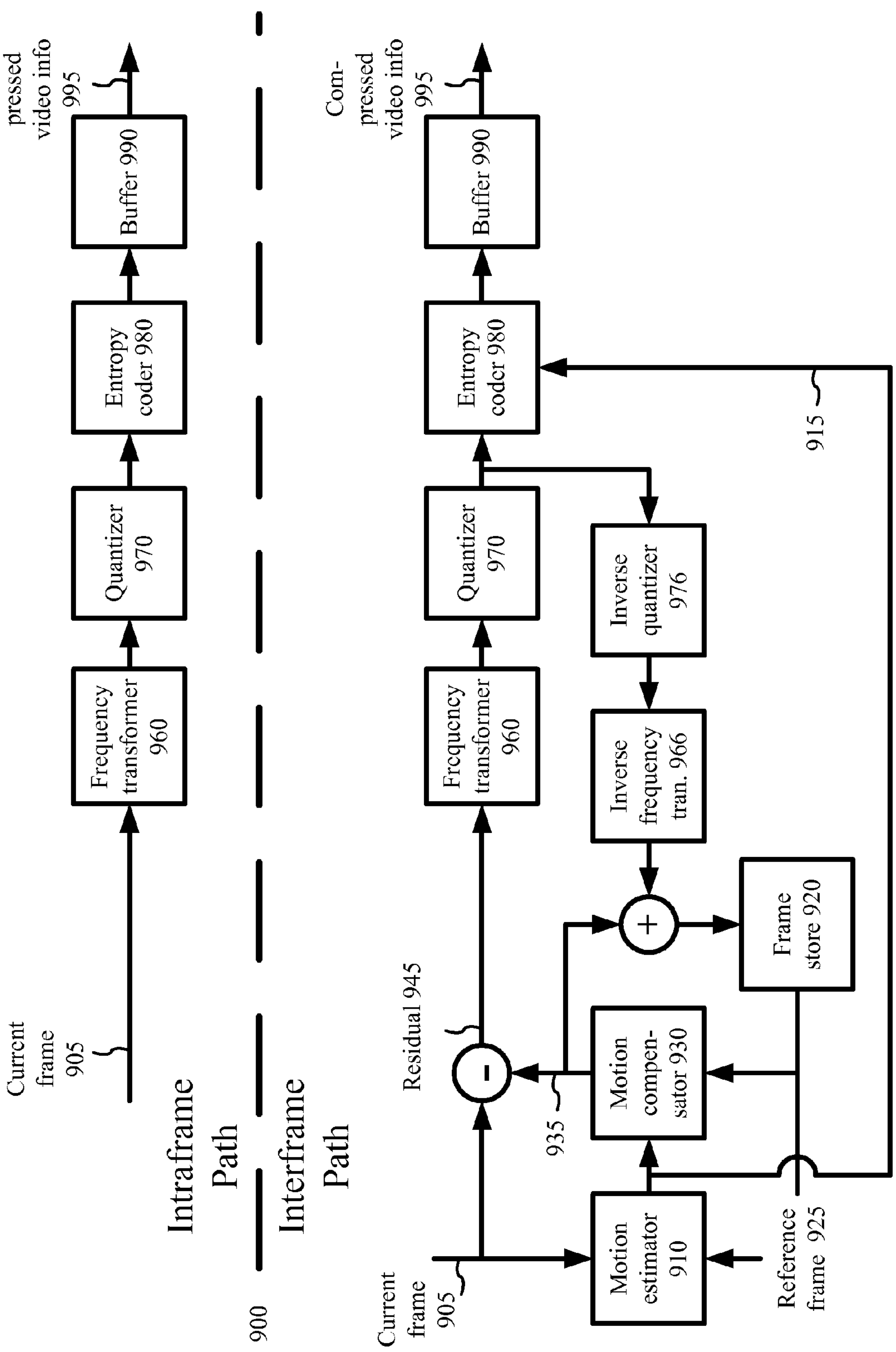

900
Intraframe Path
Current frame 905
Frequency transformer 960
Quantizer 970
Entropy coder 980
Buffer 990
Com- pressed video info 995
Interframe Path
Current frame 905
Motion estimator 910
Reference frame 925
Motion compen- sator 930
935
Residual 945
Frequency transformer 960
Quantizer 970
Entropy coder 980
Buffer 990
Com- pressed video info 995
Inverse quantizer 976
Inverse frequency tran. 966
Frame store 920
915

Figure 10

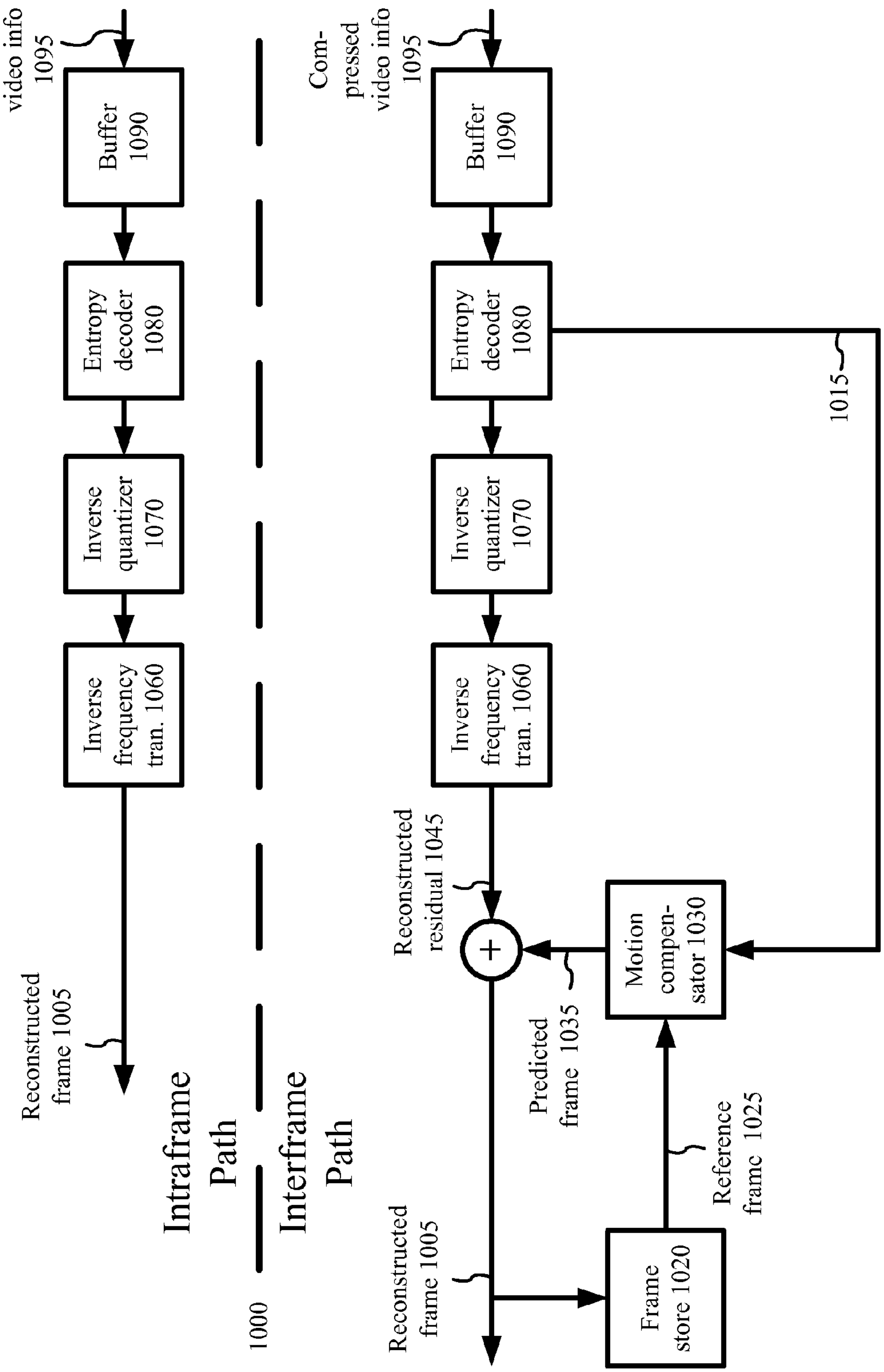

Com-
pressed
video info
1095
Buffer
1090
Entropy
decoder
1080
Inverse
quantizer
1070
Inverse
frequency
tran. 1060
Reconstructed
frame 1005
Intraframe
Path
Interframe
Path
1000
Com-
pressed
video info
1095
Buffer
1090
Entropy
decoder
1080
1015
Inverse
quantizer
1070
Inverse
frequency
tran. 1060
Reconstructed
residual 1045
Motion
compen-
sator 1030
Predicted
frame 1035
Reference
frame 1025
Reconstructed
frame 1005
Frame
store 1020

Figure 11A

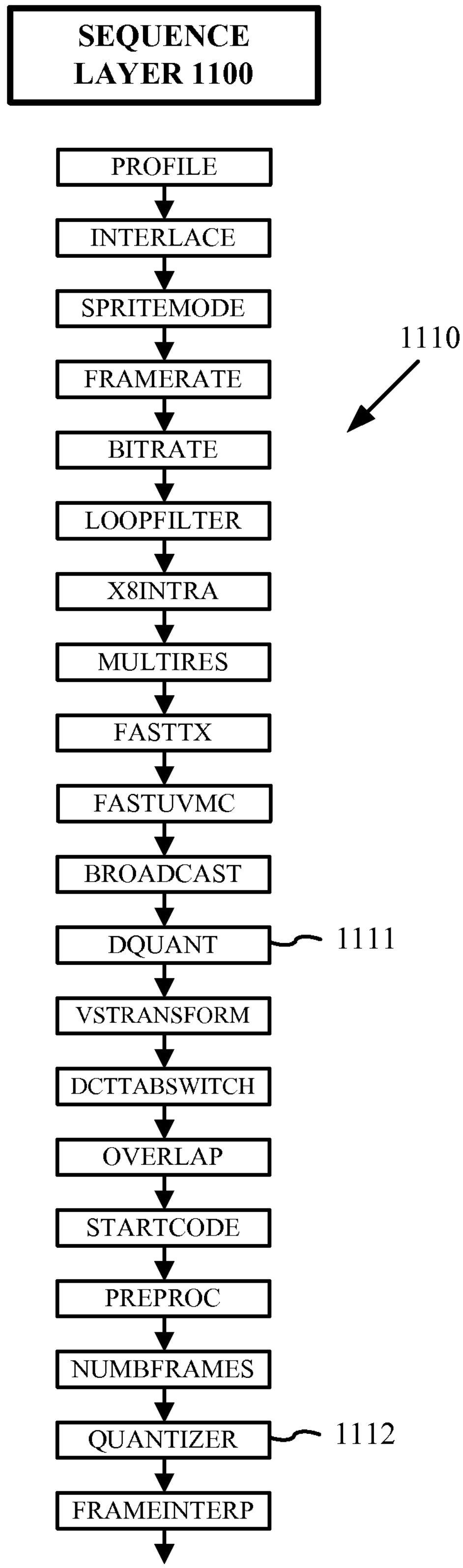

SEQUENCE LAYER 1100
PROFILE
INTERLACE
SPRITEMODE
1110
FRAMERATE
BITRATE
LOOPFILTER
X8INTRA
MULTIRES
FASTTX
FASTUVMC
BROADCAST
DQUANT
1111
VSTRANSFORM
DCTTABSWITCH
OVERLAP
STARTCODE
PREPROC
NUMBFRAMES
QUANTIZER
1112
FRAMEINTERP

Figure 11B

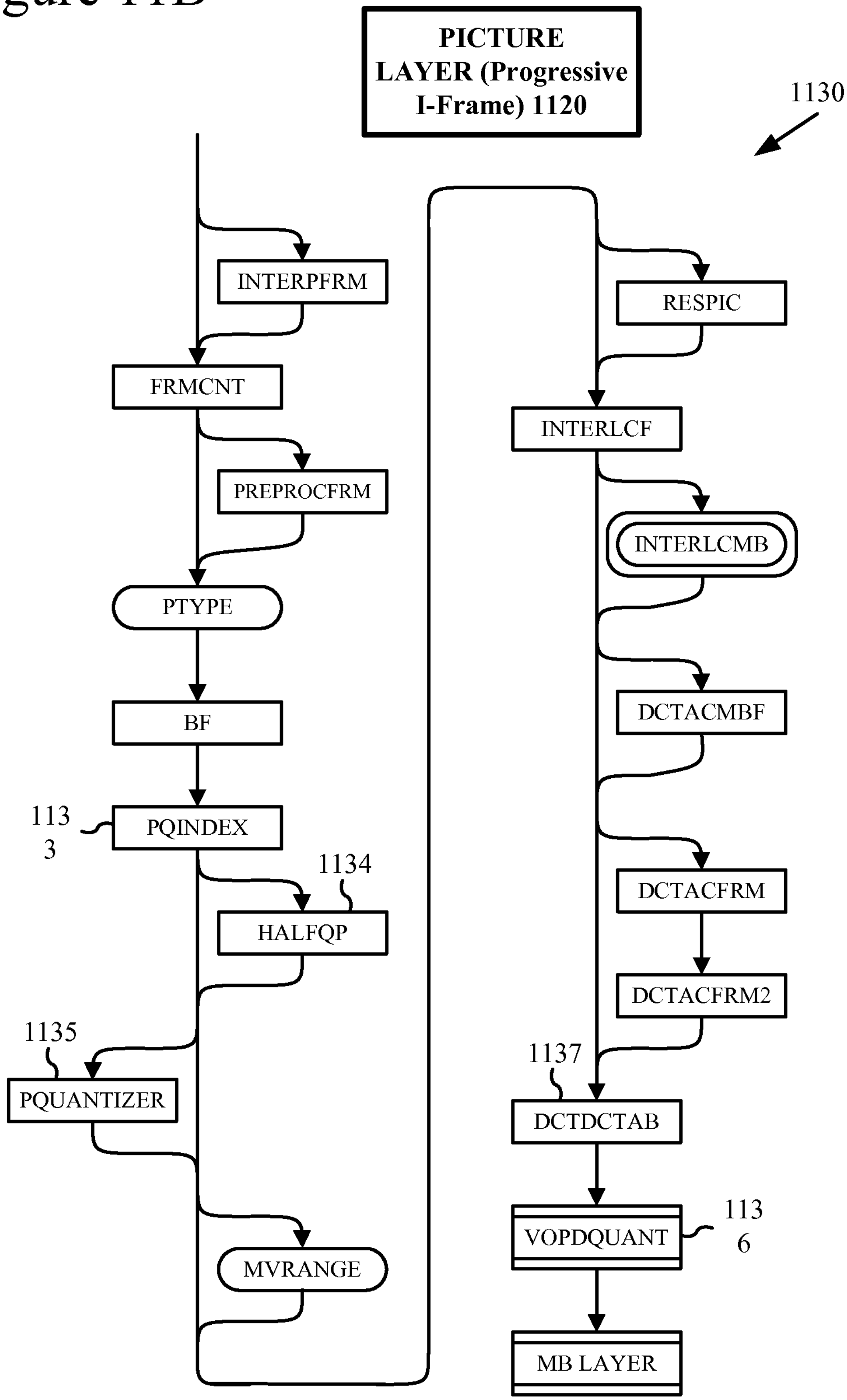

PICTURE LAYER (Progressive I-Frame) 1120
1130
INTERPFRM
FRMCNT
PREPROCFRM
PTYPE
BF
113
3
PQINDEX
1134
HALFQP
1135
PQUANTIZER
MVRANGE
RESPIC
INTERLCF
INTERLCMB
DCTACMBF
DCTACFRM
DCTACFRM2
1137
DCTDCTAB
113
6
VOPDQUANT
MB LAYER

Figure 11C

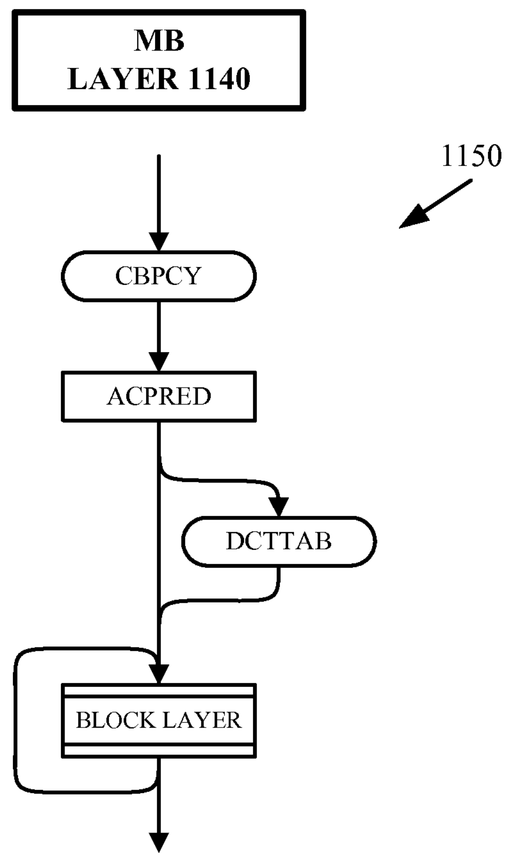


Figure 11D

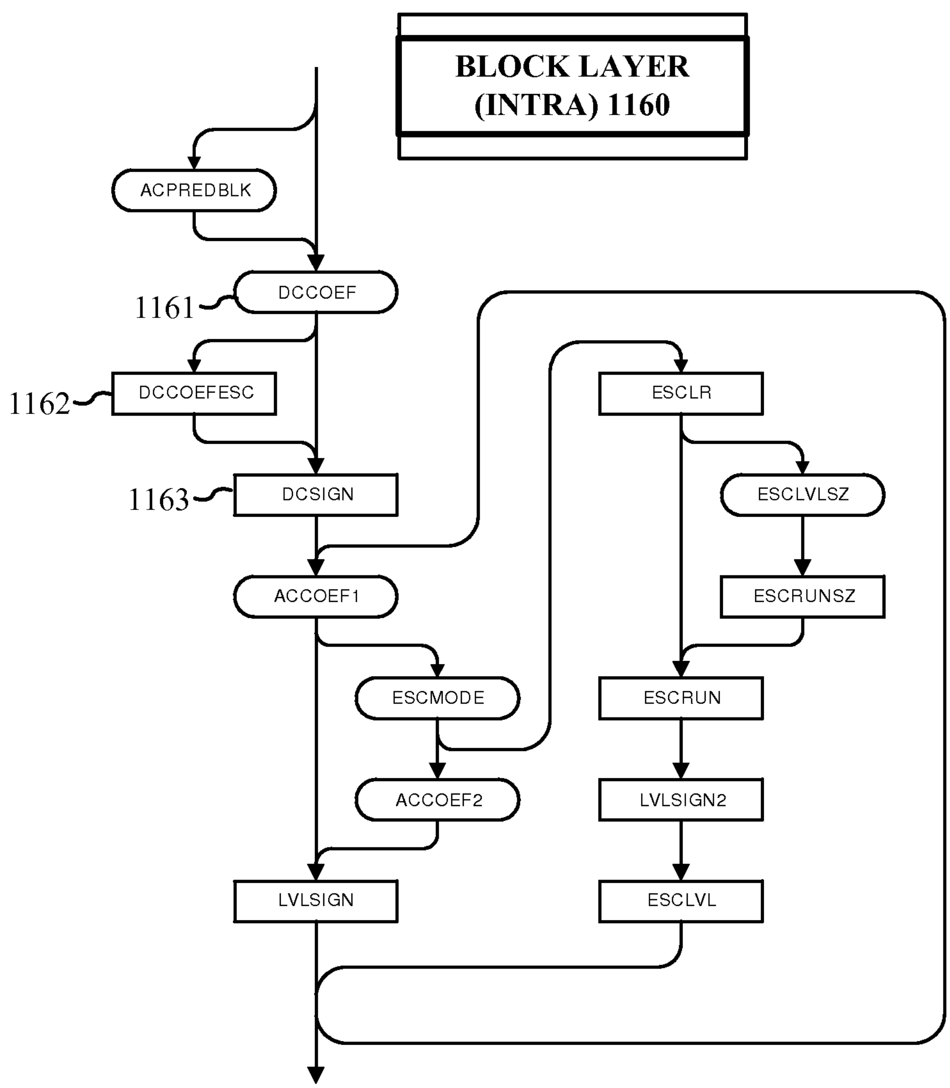

BLOCK LAYER
(INTRA) 1160
ACPREDBLK
DCCOEF
1161
DCCOEFESC
1162
DCSIGN
1163
ACCOEF1
ESCMODE
ACCOEF2
LVLSIGN
ESCLR
ESCLVLSZ
ESCRUNSZ
ESCRUN
LVLSIGN2
ESCLVL

Figure 12

```
DCDifferential = vlc_decode()
if(DCDifferential != 0) {
    if(DCDifferential == ESCAPECODE) {
        if(QUANT == 1)
            DCDifferential = flc_decode(10);
        else if(QUANT == 2)
            DCDifferential = flc_decode(9);
        else // QUANT is > 2
            DCDifferential = flc_decode(8);
    }
    else {  // DCDifferential is not ESCAPECODE
        if(QUANT == 1)
            DCDifferential = DCDifferential*4 + flc_decode(2) - 3;
        else if(QUANT == 2)
            DCDifferential = DCDifferential*2 + flc_decode(1) - 1;
    }
    DCSign = flc_decode(1)
    if (DCSign == 1)
        DCDifferential = -DCDifferential
}
```

DC COEFFICIENT SIGNALING AT SMALL QUANTIZATION STEP SIZES

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a divisional of U.S. patent application Ser. No. 10/893,168, filed Jul. 17, 2004, now U.S. Pat. No. 7,738,554, the disclosure of which is incorporated herein by reference. U.S. patent application Ser. No. 10/893,168 claims the benefit of U.S. Provisional Patent Application Ser. No. 60/488,710, filed Jul. 18, 2003, the disclosure of which is incorporated herein by reference. U.S. patent application Ser. No. 10/893,168 also is a continuation-in-part of U.S. patent application Ser. No. 10/623,195, filed Jul. 18, 2003, now U.S. Pat. No. 7,602,851, the disclosure of which is incorporated herein by reference.

COPYRIGHT AUTHORIZATION

TECHNICAL FIELD

The invention relates generally to video and other digital media coding and decoding, and more particularly relates to signaling DC coefficients in video and other digital media coding and decoding.

BACKGROUND

With the increased popularity of DVDs, music delivery over the Internet, and digital cameras, digital media have become commonplace. Engineers use a variety of techniques to process digital audio, video, and images efficiently while still maintaining quality. To understand these techniques, it helps to understand how the audio, video, and image information is represented and processed in a computer.

I. Representation of Media Information in a Computer

A computer processes media information as a series of numbers representing that information. For example, a single number may represent the intensity of brightness or the intensity of a color component such as red, green or blue for each elementary small region of a picture, so that the digital representation of the picture consists of one or more arrays of such numbers. Each such number may be referred to as a sample. For a color image, it is conventional to use more than one sample to represent the color of each elemental region, and typically three samples are used. The set of these samples for an elemental region may be referred to as a pixel, where the word "pixel" is a contraction referring to the concept of a "picture element." For example, one pixel may consist of three samples that represent the intensity of red, green and blue light necessary to represent the elemental region. Such a pixel type is referred to as an RGB pixel. Several factors affect quality, including sample depth, resolution, and frame rate (for video).

Sample depth is a property normally measured in bits that indicates the range of numbers that can be used to represent a sample. When more values are possible for the sample, quality can be higher because the number can capture more subtle variations in intensity and/or a greater range of values. Images with higher resolution tend to look crisper than other images and contain more discernable useful details. Video with higher frame rate tends to mimic the smooth motion of natural objects better than other video, and can similarly be considered to contain more detail in the temporal dimension. For all of these factors, the tradeoff for high quality is the cost of storing and transmitting the information in terms of the bit rate necessary to represent the sample depth, resolution and frame rate, as Table 1 shows.

TABLE 1

Bit rates for different quality levels of raw video

Bits Per Pixel (sample depth times samples per pixel)	Resolution (in pixels, Width × Height)	Frame Rate (in frames per second)	Bit Rate (in millions of bits per second)
8 (value 0-255, monochrome)	160 × 120	7.5	1.2
24 (value 0-255, RGB)	320 × 240	15	27.6
24 (value 0-255, RGB)	640 × 480	30	221.2
24 (value 0-255, RGB)	1280 × 720	60	1327.1

Despite the high bit rate necessary for sending high quality video (such as HDTV), companies and consumers increasingly depend on computers to create, distribute, and play back high quality content. For this reason, engineers use compression (also called source coding or source encoding) to reduce the bit rate of digital media. Compression decreases the cost of storing and transmitting the information by converting the information into a lower bit rate form. Decompression (also called decoding) reconstructs a version of the original information from the compressed form. A "codec" is an encoder/decoder system. Two categories of compression are lossless compression and lossy compression.

Lossless compression reduces the bit rate of information by removing redundancy from the information without any reduction in fidelity. For example, a series of ten consecutive pixels that are all exactly the same shade of red could be represented as a code for the particular shade of red and the number ten as a "run length" of consecutive pixels, and this series can be perfectly reconstructed by decompression from the code for the shade of red and the indicated number (ten) of consecutive pixels having that shade of red. Lossless compression techniques reduce bit rate at no cost to quality, but can only reduce bit rate up to a certain point. Decreases in bit rate are limited by the inherent amount of variability in the statistical characterization of the input data, which is referred to as the source entropy. Entropy coding is another term for lossless compression.

In contrast, with lossy compression, the quality suffers somewhat but the achievable decrease in bit rate is more dramatic. For example, a series of ten pixels, each being a slightly different shade of red, can be approximated as ten pixels with exactly the same particular approximate red color. Lossy compression techniques can be used to reduce bit rate more than lossless compression techniques, but some of the reduction in bit rate is achieved by reducing quality, and the lost quality cannot be completely recovered. Lossy compression is often used in conjunction with lossless compression—in a system design in which the lossy compression establishes an approximation of the information and lossless compression techniques are applied to represent the approximation. For example, the series of ten pixels, each a slightly different shade of red, can be represented as a code for one particular shade of red and the number ten as a run-length of consecutive pixels. In decompression, the original series would then be reconstructed as ten pixels with the same approximated red color.

II. Quantization

According to one possible definition, quantization is a term used for an approximating non-reversible mapping function commonly used for lossy compression, in which there is a specified set of possible output values, and each member of the set of possible output values has an associated set of input values that result in the selection of that particular output value. A variety of quantization techniques have been developed, including scalar or vector, uniform or non-uniform, and adaptive or non-adaptive quantization.

A. Scalar Quantizers

According to one possible definition, a scalar quantizer is an approximating functional mapping $x \rightarrow Q[x]$ of an input value x to a quantized value Q[x]. FIG. **1** shows a "staircase" I/O function (**100**) for a scalar quantizer. The horizontal axis is a number line for a real number input variable x, and the vertical axis indicates the corresponding quantized values Q[x]. The number line is partitioned by thresholds such as the threshold (**110**). Each value of x within a given range between a pair of adjacent thresholds is assigned the same quantized value Q[x]. For example, each value of x within the range (**120**) is assigned the same quantized value (**130**). (At a threshold, one of the two possible quantized values is assigned to an input x, depending on the system.) Overall, the quantized values Q[x] exhibit a discontinuous, staircase pattern. The distance the mapping continues along the number line depends on the system, typically ending after a finite number of thresholds. The placement of the thresholds on the number line may be uniformly spaced (as shown in FIG. **1**) or non-uniformly spaced.

A scalar quantizer can be decomposed into two distinct stages. The first stage is the classifier stage, in which a classifier function mapping $x \rightarrow A[x]$ maps an input x to a quantization index A[x], which is often integer-valued. In essence, the classifier segments an input number line or data set. FIG. **2***a* shows a generalized classifier (**200**) and thresholds for a scalar quantizer. As in FIG. **1**, a number line for a real number variable x is segmented by thresholds such as the threshold (**210**). Each value of x within a given range such as the range (**220**) is assigned the same quantized value Q[x]. FIG. **2***b* shows a numerical example of a classifier (**250**) and thresholds for a scalar quantizer.

In the second stage, a reconstructor functional mapping $k \rightarrow \beta[k]$ maps each quantization index k to a reconstruction value $\beta[k]$. In essence, the reconstructor places steps having a particular height relative to the input number line segments (or selects a subset of data set values) for reconstruction of each region determined by the classifier. The reconstructor functional mapping may be implemented, for example, using a lookup table. Overall, the classifier relates to the reconstructor as follows:

$$Q[x]=\beta[A[x]] \tag{1}$$

The distortion introduced by using such a quantizer may be computed with a difference-based distortion measure d(x−Q[x]). Typically, such a distortion measure has the property that d(x−Q[x]) increases as x−Q[x] deviates from zero; and typically each reconstruction value lies within the range of the corresponding classification region, so that the straight line that would be formed by the functional equation Q[x]=x will pass through every step of the staircase diagram (as shown in FIG. **1**) and therefore Q[Q[x]] will typically be equal to Q[x]. In general, a quantizer is considered better in rate-distortion terms if the quantizer results in a lower average value of distortion than other quantizers for a given bit rate of output. More formally, a quantizer is considered better if, for a source random variable X, the expected (i.e., the average or statistical mean) value of the distortion measure $\overline{D}=E_X\{d(X-Q[X])\}$ is lower for an equal or lower entropy H of A[X]. The most commonly-used distortion measure is the squared error distortion measure, for which $d(|x-y|)=|x-y|^2$. When the squared error distortion measure is used, the expected value of the distortion measure ($\overline{D}$) is referred to as the mean squared error.

B. Dead Zone+Uniform Threshold Quantizers

According to one possible definition, a dead zone plus uniform threshold quantizer ["DZ+UTQ"] is a quantizer with uniformly spaced threshold values for all classifier regions except the one containing the zero input value (which is called the dead zone ["DZ"]). A DZ+UTQ has a classifier index mapping rule x A[x] that can be expressed based on two parameters. FIG. **3** shows a staircase I/O function (**300**) for a DZ+UTQ, and FIG. **4***a* shows a generalized classifier (**400**) and thresholds for a DZ+UTQ. The parameter s, which is greater than 0, indicates the step size for all steps other than the DZ. Mathematically, all s_i are equal to s for $i \neq 0$. The parameter z, which is greater than or equal to 0, indicates the ratio of the DZ size to the size of the other steps. Mathematically, $s_0=z \cdot s$. In FIG. **4***a*, z is 2, so the DZ is twice as wide as the other classification zones. The index mapping rule $x \rightarrow A[x]$ for a DZ+UTQ can be expressed as:

$$A[x] = \mathrm{sign}(x) * \max\left(0, \left\lfloor \frac{|x|}{s} - \frac{z}{2} + 1 \right\rfloor\right), \tag{2}$$

where $\lfloor \bullet \rfloor$ denotes the smallest integer less than or equal to the argument and where sign(x) is the function defined as:

$$\mathrm{sign}(x) = \begin{cases} +1, & \text{for } x \geq 0, \\ -1, & \text{for } x < 0. \end{cases} \tag{3}$$

FIG. **4***b* shows a numerical example of a classifier (**450**) and thresholds for a DZ+UTQ with s=1 and z=2. FIGS. **1**, **2***a*, and **2***b* show a special case DZ+UTQ with z=1. Quantizers of the UTQ form have good performance for a variety of statistical sources. In particular, the DZ+UTQ form is optimal for the statistical random variable source known as the Laplacian source.

In some system designs (not shown), an additional consideration may be necessary to fully characterize a DZ+UTQ classification rule. For practical reasons there may be a need to limit the range of values that can result from the classification function A[x] to some reasonable finite range. This limitation is referred to as clipping. For example, in some such systems the classification rule could more precisely be defined as:

$$A[x] = \mathrm{sign}(x) * \min\left[g, \max\left(0, \left\lfloor \frac{|x|}{s} - \frac{z}{2} + 1 \right\rfloor\right)\right], \tag{4}$$

where g is a limit on the absolute value of A[x]. In much of the theoretical analysis presented herein, consideration of clipping is omitted as it unduly complicates the analysis without advancing the explanation. Moreover, although the clipping shown in the above example is symmetric about zero, the clipping does not need to be symmetric, and often is not exactly symmetric. For example, a common clipping range would be such that the value of A[x] is limited to some range from -2^B to $+2^B-1$ so that A[x] can be represented as an integer using a two's complement representation that uses B+1 bits, where B+1 may be equal to 8 or 16 or another particular selected number of bits.

C. Reconstruction Rules

Different reconstruction rules may be used to determine the reconstruction value for each quantization index. These include the optimal reconstruction rule and the single offset reconstruction rule (of which the mid-point reconstruction rule is an example). FIG. **5** shows reconstruction points according to different reconstruction rules for a particular shape of a source probability distribution function $f(x)$. For a range of values between two thresholds t_j and t_{j+1}, the reconstruction value $r_{j,mid}$ according to the mid-point reconstruction rule bisects the range (thus, $r_{j,mid}=(t_j+t_{j+1})/2$). For the example probability distribution function shown in FIG. **5**, this fails to account for the fact that values to the left of the mid-point are more likely than values to the right of the mid-point. The reconstruction value $r_{j,opt}$ according to the optimal reconstruction rule accounts for the probability distribution.

In general, a probability distribution function ["pdf"] indicates the probabilities for the different values of a variable. One possible definition of the optimal reconstruction value $r_{j,opt}$ for each region between two neighboring thresholds t_j and t_{j+1} for a pdf $f(x)$ can be expressed as:

$$r_{j,opt} = \min_y^{-1} \int_{t_j}^{t_{j+1}} d(x-y) f(x) dx. \quad (5)$$

Assuming that the pdf $f(x)$ for a given source is symmetric around zero, one possible definition of the optimal reconstruction rule of a DZ+UTQ for a symmetric, difference-based distortion measure $d(|x-y|)$ is:

$$\beta[k] = \begin{cases} \min_y^{-1} \int_0^{\frac{zs}{2}} [d(|x-y|) + d(|y-x|)] f(x) dx, & \text{for } k = 0, \\ \text{sign}(k) \min_y^{-1} \int_{\frac{zs}{2}+(|k|-1)s}^{\frac{zs}{2}+|k|s} d(|x-y|) f(x) dx, & \text{for } k \neq 0. \end{cases} \quad (6),$$

where y is the quantized value Q[x], and where the rule finds the quantized value Q[x] that results in the smallest distortion according to the distortion measure. Typically, the optimal quantized value for β[0] is equal to 0, and that will be assumed to be true for the remainder of this description. For minimizing mean squared error, the optimal reconstruction rule sets the reconstruction value for each region equal to the conditional mean of the input values in that region. Stated more precisely, the optimal reconstruction value $r_{j,opt}$ for the region between two neighboring thresholds t_j and t_{j+1} for a pdf $f(x)$ when using the mean squared error distortion measure is given by

$$r_{j,opt} = \frac{\int_{t_j}^{t_{j+1}} x \cdot f(x) dx}{\int_{t_j}^{t_{j+1}} f(x) dx}. \quad (7)$$

According to one possible definition for a DZ+UTQ, the single-offset reconstruction rule is based on an offset parameter A, where ordinarily 0<Δ≤s/2, and the rule is:

$$\beta[k] = \begin{cases} 0, & \text{for } k = 0, \\ \text{sign}(k)\left[\left(|k| + \frac{z}{2} - 1\right)s + \Delta\right], & \text{for } k \neq 0. \end{cases} \quad (8).$$

The mid-point reconstruction rule is a special case of the single-offset reconstruction rule, specified by Δ=s/2. Mid-point reconstruction is commonly used for convenience due to its simplicity. And, in the limit as s becomes very small, the performance of the mid-point rule becomes optimal under a variety of well-behaved mathematical conditions.

D. Specifying Reconstruction Values, Constructing Classifiers

Standards and product specifications that focus only on achieving interoperability will often specify reconstruction values without necessarily specifying the classification rule. In other words, some specifications may define the functional mapping k→β[k] without defining the functional mapping x A[x]. This allows a decoder built to comply with the standard/specification to reconstruct information correctly. In contrast, encoders are often given the freedom to change the classifier in any way that they wish, while still complying with the standard/specification.

Numerous systems for adjusting quantization thresholds have been developed. Many standards and products specify reconstruction values that correspond to a typical mid-point reconstruction rule (e.g., for a typical simple classification rule) for the sake of simplicity. For classification, however, the thresholds can in fact be adjusted so that certain input values will be mapped to more common (and hence, lower bit rate) indices, which makes the reconstruction values closer to optimal. FIG. **6** shows such adjusted thresholds for a classifier (**600**). The original thresholds (such as old t_j) are situated halfway between the reconstruction points. The thresholds are moved outward on the number line, away from **0**. Before the adjustment, a marginal value (shown between the old t_j and the new t_j) is mapped to r_j. After the adjustment, the marginal value is mapped to T_0. The decoder performs reconstruction without knowledge of the adjustments done in the encoder.

For optimal encoding, an encoder may adjust quantization thresholds to optimally fit a given set of reconstruction values as follows. The probability p_j for the source random variable X to fall within a range j between t_j and t_{j+1} (where $t_{j+1}>t_j$) for a source pdf $f(x)$ is:

$$p_j = \int_{t_j}^{t_{j+1}} f(x) dx, \quad (9)$$

and the number of bits necessary to represent an event with probability p_j in an ideal lossless communication system may be quantified as:

$$h_j = \log_2 \frac{1}{p_j}, \quad (10)$$

where the h_j is expressed in terms of bits. The total entropy of the classifier is then given by

$$H = \sum_j p_j \cdot h_j \text{ bits.} \quad (11)$$

In general, if the encoder is required to use b_j bits to indicate the selection of the reconstruction value r_j, the encoder may evaluate and optimize its thresholds according to minimization of the rate-distortion relation $D+\lambda R$, where D indicates distortion, R indicates bit usage, and λ is a tuning parameter for favoring a particular selected balance between distortion and bit rate. For each particular threshold t_{j+1} between two points r_j and r_{j+i}, the encoder can set t_{j+1} to the x that satisfies:

$$d(x-r_j)+\lambda b_j=d(x-r_{j+1})+\lambda b_{j+1} \quad (12).$$

In an ideal design, b_j will be approximately equal to h_j, and modern lossless coding techniques can be used to very nearly achieve this goal. In a design using some non-ideal lossless coding technique to represent the output of the classifier, b_j may have some other value.

Note in summation that optimal decision thresholds can be selected using equation (12), that optimal reconstruction values can be selected using equation (5) or (7), and that optimal bit usage can be computed by setting b_j equal to h_j as given by equation (10) or to the number of bits used in some other lossless code (such as a Huffman code designed using equation (9) or a fixed-length code). In some highly-optimized scalar quantizer system designs, reconstruction values (initially uniformly spaced) are analyzed to adjust thresholds in encoder analysis, then use of the adjusted thresholds is analyzed to set the number of bits needed to represent the output of the classifier using lossless coding and to set the reconstruction values in decoder analysis. The new reconstruction values are then analyzed to adjust thresholds, and so on, until the thresholds and/or reconstruction values stabilize across iterations.

III. Compression and Decompression Systems

In general, video compression techniques include "intra-picture" compression and "inter-picture" compression, where a picture is, for example, a progressively scanned video frame, an interlaced video frame (having alternating lines for video fields), or an interlaced video field. For progressive frames, intra-picture compression techniques compress individual frames (typically called I-frames or key frames), and inter-picture compression techniques compress frames (typically called predicted frames, P-frames, or B-frames) with reference to preceding and/or following frames (typically called reference or anchor frames).

Both intra and inter-picture compression techniques often use a reversible frequency transform operation, which generates a set of frequency domain (i.e., spectral) coefficients. For intra-picture compression, the transform is typically applied to a block of samples. For inter-picture compression, the transform is typically applied to a block of motion-compensation prediction residual information. A discrete cosine transform ["DCT"] is a type of frequency transform. The resulting blocks of transform coefficients are quantized and entropy encoded. A decoder typically entropy decodes and reconstructs transform coefficients (e.g., DCT coefficients) that were quantized and performs an inverse frequency transform such as an IDCT.

A. Intra-Compression in Windows Media Video, Version 8 ["WMV8"]

Microsoft Corporation's Windows Media Video, Version 8 ["WMV8"] includes a video encoder and a video decoder. The WMV8 encoder uses intra-frame and inter-frame compression, and the WMV8 decoder uses intra-frame and inter-frame decompression.

FIG. **7** illustrates block-based intraframe compression (**700**) of a 8×8 block (**705**) of samples in a frame in the WMV8 encoder. The WMV8 encoder here splits a frame into 8×8 blocks of samples and applies an 8×8 DCT (**710**) to individual blocks such as the block (**705**). The encoder quantizes (**720**) the DCT coefficients (**715**), resulting in an 8×8 block of quantized DCT coefficients (**725**). For example, the encoder applies a uniform, scalar quantization step size to each coefficient.

Further encoding varies depending on whether a coefficient is a DC coefficient, an AC coefficient in the top row or left column, or another AC coefficient. The encoder encodes the DC coefficient (**726**) as a differential from the DC coefficient (**736**) of a neighboring 8×8 block, which is a previously encoded top or left neighbor block. The encoder entropy encodes (**740**) the differential. The entropy encoder can encode the left column or top row of AC coefficients as differentials from a corresponding column or row of a neighboring 8×8 block. FIG. **7** shows the left column (**727**) of AC coefficients encoded as differentials (**747**) from the left column (**737**) of the neighboring (actually situated to the left) block (**735**). The encoder scans (**750**) the 8×8 block (**745**) of predicted, quantized AC DCT coefficients into a one-dimensional array (**755**) and then entropy encodes the scanned coefficients using a variation of run length coding (**760**). The encoder selects an entropy code from one or more run/level/last tables (**765**) and outputs the entropy code.

A WMV8 decoder (not shown) produces a reconstructed version of the original block (**705**). The decoder determines the DC predictor for the DC coefficient and decodes the DC differential. In particular, the following pseudocode illustrates the DC differential decoding process in WMV8.

```
DCDifferential = vlc_decode( )
if (DCDifferential == ESCAPECODE)
    DCDifferential = flc_decode(8)
DCSign = flc_decode(1)
if (DCSign == 1)
    DCDifferential = -DCDifferential
```

The WMV8 decoder combines the DC differential with the predictor for the DC coefficient to reconstruct the DC coefficient. The decoder entropy decodes the AC coefficients using one or more run/level/last tables, and scans the coefficients back into a two-dimensional array. The WMV decoder computes a predictor for the top row or left column of AC coefficients if appropriate. The decoder inverse quantizes the coefficients and performs an IDCT.

While DC differential coding and decoding as in WMV8 provide good performance in many scenarios, there are opportunities for improvement. In particular, DC differential coding and decoding as in WMV8 are not easily applied for smaller quantization sizes. This is because at the smaller quantization sizes, VLC code table size for DC differentials becomes inefficiently large for many devices for practical applications.

B. Video Codec Standards

Various standards specify aspects of video decoders as well as formats for compressed video information. These standards include H.261, MPEG-1, H.262 (also called MPEG-2), H.263, and MPEG-4. Directly or by implication, these standards may specify certain encoder details, but other encoder details are not specified. Different standards incorporate different techniques, but each standard typically specifies some kind of inverse frequency transform and entropy decoding. For information, see the respective standard documents.

SUMMARY

Described tools and techniques relate to coding of DC coefficients in video and other digital media coding. More particularly, the techniques and tools relate to signaling for DC coefficients at small quantization step sizes. The techniques and tools can be used in combination or independently.

According to a first set of tools and techniques, a tool such as a video encoder or decoder processes a first code that indicates a DC differential for a DC coefficient and a second code that indicates a value refinement for the DC differential. For example, a video encoder encodes the DC coefficient based at least in part on the first and second codes. Or, a video decoder reconstructs the DC coefficient during decoding based at least in part on the first and second codes.

According to a second set of tools and techniques, a tool such as a video encoder or decoder processes a VLC for a first DC differential for a first DC coefficient at a first quantization step size. The tool uses a VLC table that indicates DC differentials for DC coefficients at and above a second quantization step size larger than the first quantization step size.

According to a third set of tools and techniques, a tool such as a video encoder or decoder processes a code for a DC differential for a DC coefficient, where the code is a FLC having a length that varies depending on quantization step size. For example, the FLC indicates a refinement value for the DC differential. Or, when an escape code is used for the DC differential, the FLC indicates a value for the DC differential.

Additional features and advantages will be made apparent from the following detailed description of various embodiments that proceeds with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a chart showing a staircase I/O function for a scalar quantizer according to the prior art.

FIGS. **2***a* and **2***b* are charts showing classifiers and thresholds for scalar quantizers according to the prior art.

FIG. **3** is a chart showing a staircase I/O function for a DZ+UTQ according to the prior art.

FIGS. **4***a* and **4***b* are charts showing classifiers and thresholds for DZ+UTQs according to the prior art.

FIG. **5** is a chart showing reconstruction points for different reconstruction rules for a given pdf shape according to the prior art.

FIG. **6** is a chart showing adjustments to a classifier for a scalar quantizer according to the prior art.

FIG. **7** is a block diagram showing block-based intra-compression according to the prior art.

FIG. **8** is a block diagram of a suitable computing environment in which several described embodiments may be implemented.

FIGS. **9** and **10** are block diagrams of a video encoder system and a video decoder system, respectively, in conjunction with which several described embodiments may be implemented.

FIGS. **11**A-**11**D are diagrams for different syntax layers of a bitstream.

FIG. **12** is a listing of DC differential decoding pseudocode.

DETAILED DESCRIPTION

Described embodiments relate to techniques and tools for signaling DC coefficients at small quantization step sizes. The various techniques and tools can be used in combination or independently.

I. Computing Environment

FIG. **8** illustrates a generalized example of a suitable computing environment (**800**) in which several of the described embodiments may be implemented. The computing environment (**800**) is not intended to suggest any limitation as to scope of use or functionality, as the techniques and tools may be implemented in diverse general-purpose or special-purpose computing environments.

With reference to FIG. **8**, the computing environment (**800**) includes at least one processing unit (**810**) and memory (**820**). In FIG. **8**, this most basic configuration (**830**) is included within a dashed line. The processing unit (**810**) executes computer-executable instructions and may be a real or a virtual processor. In a multi-processing system, multiple processing units execute computer-executable instructions to increase processing power. The memory (**820**) may be volatile memory (e.g., registers, cache, RAM), non-volatile memory (e.g., ROM, EEPROM, flash memory, etc.), or some combination of the two. The memory (**820**) stores software (**880**) implementing an encoder and/or decoder with special signaling of DC coefficients at small quantization step sizes.

A computing environment may have additional features. For example, the computing environment (**800**) includes storage (**840**), one or more input devices (**850**), one or more output devices (**860**), and one or more communication connections (**870**). An interconnection mechanism (not shown) such as a bus, controller, or network interconnects the components of the computing environment (**800**). Typically, operating system software (not shown) provides an operating environment for other software executing in the computing environment (**800**), and coordinates activities of the components of the computing environment (**800**).

The storage (**840**) may be removable or non-removable, and includes magnetic disks, magnetic tapes or cassettes, CD-ROMs, DVDs, or any other medium which can be used to store information and which can be accessed within the computing environment (**800**). The storage (**840**) stores instructions for the software (**880**) implementing the encoder and/or decoder.

The input device(s) (**850**) may be a touch input device such as a keyboard, mouse, pen, or trackball, a voice input device, a scanning device, or another device that provides input to the computing environment (**800**). For audio or video encoding, the input device(s) (**850**) may be a sound card, video card, TV tuner card, or similar device that accepts audio or video input in analog or digital form, or a CD-ROM or CD-RW that reads audio or video samples into the computing environment (**800**). The output device(s) (**860**) may be a display, printer, speaker, CD-writer, or another device that provides output from the computing environment (**800**).

The communication connection(s) (**870**) enable communication over a communication medium to another computing entity. The communication medium conveys information such as computer-executable instructions, audio or video input or output, or other data in a modulated data signal. A modulated data signal is a signal that has one or more of its characteristics set or changed in such a manner as to encode information in the signal. By way of example, and not limitation, communication media include wired or wireless techniques implemented with an electrical, optical, RF, infrared, acoustic, or other carrier.

The techniques and tools can be described in the general context of computer-readable media. Computer-readable media are any available media that can be accessed within a computing environment. By way of example, and not limitation, with the computing environment (**800**), computer-readable media include memory (**820**), storage (**840**), communication media, and combinations of any of the above.

The techniques and tools can be described in the general context of computer-executable instructions, such as those included in program modules, being executed in a computing environment on a target real or virtual processor. Generally, program modules include routines, programs, libraries, objects, classes, components, data structures, etc. that perform particular tasks or implement particular abstract data types. The functionality of the program modules may be combined or split between program modules as desired in various embodiments. Computer-executable instructions for program modules may be executed within a local or distributed computing environment.

II. Video Encoder and Decoder

FIG. **9** is a block diagram of a generalized video encoder system (**900**), and FIG. **10** is a block diagram of a video decoder system (**1000**), in conjunction with which various described embodiments may be implemented.

The relationships shown between modules within the encoder and decoder indicate the main flow of information in the encoder and decoder; other relationships are not shown for the sake of simplicity. In particular, FIGS. **9** and **10** usually do not show side information indicating the encoder settings, modes, tables, etc. used for a video sequence, frame, macroblock, block, etc. Such side information is sent in the output bitstream, typically after entropy encoding of the side information. The format of the output bitstream can be a Windows Media Video version 9 or other format.

The encoder (**900**) and decoder (**1000**) are block-based and use a 4:2:0 macroblock format, with each macroblock including four 8×8 luminance blocks (at times treated as one 16×16 macroblock) and two 8×8 chrominance blocks. Alternatively, the encoder (**900**) and decoder (**1000**) are object-based, use a different macroblock or block format, or perform operations on sets of pixels of different size or configuration than 8×8 blocks and 16×16 macroblocks.

Depending on implementation and the type of compression desired, modules of the encoder or decoder can be added, omitted, split into multiple modules, combined with other modules, and/or replaced with like modules. In alternative embodiments, encoders or decoders with different modules and/or other configurations of modules perform one or more of the described techniques.

A. Video Encoder

FIG. **9** is a block diagram of a general video encoder system (**900**) that can perform joint entropy coding and bitstream formation operations for variable-size transform information. The encoder system (**900**) receives a sequence of video frames including a current frame (**905**), and produces compressed video information (**995**) as output. Particular embodiments of video encoders typically use a variation or supplemented version of the generalized encoder (**900**).

The encoder system (**900**) compresses predicted frames and key frames. For the sake of presentation, FIG. **9** shows a path for key frames through the encoder system (**900**) and a path for forward-predicted frames. Many of the components of the encoder system (**900**) are used for compressing both key frames and predicted frames. The exact operations performed by those components can vary depending on the type of information being compressed.

A predicted frame (also called p-frame, b-frame for bi-directional prediction, or inter-coded frame) is represented in terms of prediction (or difference) from one or more other frames. A prediction residual is the difference between what was predicted and the original frame. In contrast, a key frame (also called an I-frame or intra-coded frame) is compressed without reference to other frames.

If the current frame (**905**) is a forward-predicted frame, a motion estimator (**910**) estimates motion of macroblocks or other sets of pixels of the current frame (**905**) with respect to a reference frame, which is a reconstructed previous frame (**925**) buffered in the frame store (**920**). In alternative embodiments, the reference frame is a later frame or the current frame is bi-directionally predicted. The motion estimator (**910**) can estimate motion by pixel, ½ pixel, ¼ pixel, or other increments, and can switch the precision of the motion estimation on a frame-by-frame basis or other basis. The precision of the motion estimation can be the same or different horizontally and vertically. The motion estimator (**910**) outputs as side information motion information (**915**) such as motion vectors. A motion compensator (**930**) applies the motion information (**915**) to the reconstructed previous frame (**925**) to form a motion-compensated current frame (**935**). The prediction is rarely perfect, however, and the difference between the motion-compensated current frame (**935**) and the original current frame (**905**) is the prediction residual (**945**). Alternatively, a motion estimator and motion compensator apply another type of motion estimation/compensation.

For DC coefficients at small quantization step sizes, the encoder signals DC coefficients using a syntax and code tables such as those described below. In particular, the encoder uses the code tables and produces an output bitstream in compliance with the syntax below.

A frequency transformer (**960**) converts the spatial domain video information into frequency domain (i.e., spectral) data. For block-based video frames, the frequency transformer (**960**) applies a DCT or variant of DCT to blocks of the pixel data or prediction residual data, producing blocks of DCT coefficients. Alternatively, the frequency transformer (**960**) applies another conventional frequency transform such as a Fourier transform or uses wavelet or subband analysis. In embodiments in which the encoder uses spatial extrapolation (not shown in FIG. **9**) to encode blocks of key frames, the frequency transformer (**960**) can apply a re-oriented frequency transform such as a skewed DCT to blocks of prediction residuals for the key frame. The frequency transformer (**960**) applies an 8×8, 8×4, 4×8, or other size frequency transforms (e.g., DCT) to prediction residuals for predicted frames.

A quantizer (**970**) then quantizes the blocks of spectral data coefficients. The quantizer applies uniform, scalar quantization to the spectral data with a step-size that varies on a frame-by-frame basis or other basis. Alternatively, the quantizer applies another type of quantization to the spectral data coefficients, for example, a non-uniform, vector, or non-adaptive quantization, or directly quantizes spatial domain data in an encoder system that does not use frequency transformations. In addition to adaptive quantization, the encoder (**900**) can use frame dropping, adaptive filtering, or other techniques for rate control.

If a given macroblock in a predicted frame has no information of certain types (e.g., no motion information for the macroblock and no residual information), the encoder (**900**) may encode the macroblock as a skipped macroblock. If so, the encoder signals the skipped macroblock in the output bitstream of compressed video information (**995**).

When a reconstructed current frame is needed for subsequent motion estimation/compensation, an inverse quantizer (**976**) performs inverse quantization on the quantized spectral data coefficients. An inverse frequency transformer (**966**) then performs the inverse of the operations of the frequency transformer (**960**), producing a reconstructed prediction residual (for a predicted frame) or reconstructed samples (for an intra-coded frame). If the frame (**905**) being encoded is an intra-coded frame, then the reconstructed samples form the reconstructed current frame (not shown). If the frame (**905**) being encoded is a predicted frame, the reconstructed prediction residual is added to the motion-compensated predictions (**935**) to form the reconstructed current frame. The frame store (**920**) buffers the reconstructed current frame for use in predicting a next frame. In some embodiments, the encoder applies a deblocking filter to the reconstructed frame to adaptively smooth discontinuities between the blocks of the frame.

The entropy coder (**980**) compresses the output of the quantizer (**970**) as well as certain side information (e.g., motion information (**915**), spatial extrapolation modes, quantization step size). Typical entropy coding techniques include arithmetic coding, differential coding, Huffman coding, run length coding, LZ coding, dictionary coding, and combinations of the above. The entropy coder (**980**) typically uses different coding techniques for different kinds of information (e.g., DC coefficients, AC coefficients, different kinds of side information), and can choose from among multiple code tables within a particular coding technique.

The entropy coder (**980**) puts compressed video information (**995**) in the buffer (**990**). A buffer level indicator is fed back to bit rate adaptive modules. The compressed video information (**995**) is depleted from the buffer (**990**) at a constant or relatively constant bit rate and stored for subsequent streaming at that bit rate. Therefore, the level of the buffer (**990**) is primarily a function of the entropy of the filtered, quantized video information, which affects the efficiency of the entropy coding. Alternatively, the encoder system (**900**) streams compressed video information immediately following compression, and the level of the buffer (**990**) also depends on the rate at which information is depleted from the buffer (**990**) for transmission.

Before or after the buffer (**990**), the compressed video information (**995**) can be channel coded for transmission over the network. The channel coding can apply error detection and correction data to the compressed video information (**995**).

B. Video Decoder

FIG. **10** is a block diagram of a general video decoder system (**1000**). The decoder system (**1000**) receives information (**1095**) for a compressed sequence of video frames and produces output including a reconstructed frame (**1005**). Particular embodiments of video decoders typically use a variation or supplemented version of the generalized decoder (**1000**).

The decoder system (**1000**) decompresses predicted frames and key frames. For the sake of presentation, FIG. **10** shows a path for key frames through the decoder system (**1000**) and a path for forward-predicted frames. Many of the components of the decoder system (**1000**) are used for decompressing both key frames and predicted frames. The exact operations performed by those components can vary depending on the type of information being decompressed.

A buffer (**1090**) receives the information (**1095**) for the compressed video sequence and makes the received information available to the entropy decoder (**1080**). The buffer (**1090**) typically receives the information at a rate that is fairly constant over time, and includes a jitter buffer to smooth short-term variations in bandwidth or transmission. The buffer (**1090**) can include a playback buffer and other buffers as well. Alternatively, the buffer (**1090**) receives information at a varying rate. Before or after the buffer (**1090**), the compressed video information can be channel decoded and processed for error detection and correction.

The entropy decoder (**1080**) entropy decodes entropy-coded quantized data as well as entropy-coded side information (e.g., motion information (**1015**), spatial extrapolation modes, quantization step size), typically applying the inverse of the entropy encoding performed in the encoder. Entropy decoding techniques include arithmetic decoding, differential decoding, Huffman decoding, run length decoding, LZ decoding, dictionary decoding, and combinations of the above. The entropy decoder (**1080**) frequently uses different decoding techniques for different kinds of information (e.g., DC coefficients, AC coefficients, different kinds of side information), and can choose from among multiple code tables within a particular decoding technique.

If the frame (**1005**) to be reconstructed is a forward-predicted frame, a motion compensator (**1030**) applies motion information (**1015**) to a reference frame (**1025**) to form a prediction (**1035**) of the frame (**1005**) being reconstructed. For example, the motion compensator (**1030**) uses a macroblock motion vector to find a macroblock in the reference frame (**1025**). A frame buffer (**1020**) stores previous reconstructed frames for use as reference frames. The motion compensator (**1030**) can compensate for motion at pixel, ½ pixel, ¼ pixel, or other increments, and can switch the precision of the motion compensation on a frame-by-frame basis or other basis. The precision of the motion compensation can be the same or different horizontally and vertically. Alternatively, a motion compensator applies another type of motion compensation. The prediction by the motion compensator is rarely perfect, so the decoder (**1000**) also reconstructs prediction residuals.

When the decoder needs a reconstructed frame for subsequent motion compensation, the frame store (**1020**) buffers the reconstructed frame for use in predicting a next frame. In some embodiments, the encoder applies a deblocking filter to the reconstructed frame to adaptively smooth discontinuities between the blocks of the frame.

An inverse quantizer (**1070**) inverse quantizes entropy-decoded data. In general, the inverse quantizer applies uniform, scalar inverse quantization to the entropy-decoded data with a step-size that varies on a frame-by-frame basis or other basis. Alternatively, the inverse quantizer applies another type of inverse quantization to the data, for example, a non-uniform, vector, or non-adaptive inverse quantization, or directly inverse quantizes spatial domain data in a decoder system that does not use inverse frequency transformations.

An inverse frequency transformer (**1060**) converts the quantized, frequency domain data into spatial domain video information. For block-based video frames, the inverse frequency transformer (**1060**) applies an IDCT or variant of IDCT to blocks of the DCT coefficients, producing pixel data or prediction residual data for key frames or predicted frames, respectively. Alternatively, the frequency transformer (**1060**) applies another conventional inverse frequency transform such as a Fourier transform or uses wavelet or subband synthesis. In embodiments in which the decoder uses spatial extrapolation (not shown in FIG. **10**) to decode blocks of key frames, the inverse frequency transformer (**1060**) can apply a re-oriented inverse frequency transform such as a skewed IDCT to blocks of prediction residuals for the key frame. The inverse frequency transformer (**1060**) applies an 8×8, 8×4, 4×8, or other size inverse frequency transforms (e.g., IDCT) to prediction residuals for predicted frames.

The decoder (**1000**) processes DC coefficient information when quantization step sizes are small, for example, as described below.

III. Example Bitstream Syntax and Semantics

An example bitstream includes information for a sequence of compressed progressive video frames or other pictures. The bitstream is organized into several hierarchical layers that are decoded by a decoder such as the decoder (**1000**) of FIG. **10**. The highest layer is the sequence layer, which has information for the overall sequence of frames. Additionally, each compressed video frame is made up of data that is structured into three hierarchical layers. From top to bottom the layers are: picture, macroblock, and block.

FIG. **11**A is a syntax diagram for the sequence layer (**1100**), which includes a sequence header (**1110**) followed by data for the picture layer (see FIG. **11**B). The sequence header (**1110**) includes several sequence-level elements that are processed by the decoder and used to decode the sequence, including a macroblock quantization (DQUANT) element (**1111**) and quantizer specifier (QUANTIZER) element (**1112**). DQUANT (**1111**) is a 2-bit field that indicates whether or not the quantization step size can vary within a frame. There are three possible values for DQUANT. If DQUANT=0, then the only one quantization step size (i.e. the frame quantization step size) can be used per frame. If DQUANT=1 or 2, then it is possible to quantize each of the macroblocks in the frame differently.

The QUANTIZER (**1112**) is a 2-bit fixed length code ["FLC"] field that indicates the quantizer used for the sequence. The quantizer types are encoded according to the following Table 2.

TABLE 2

Quantizer Specification	
FLC	Quantizer specification
00	Quantizer implicitly specified at frame level
01	Quantizer explicitly specified at frame level
10	5 QP deadzone quantizer used for all frames
11	3 QP deadzone quantizer used for all frames

FIG. **11**B is a syntax diagram for the picture layer (**1120**) for a progressive intra-frame ["progressive I-frame"]. Syntax diagrams for other pictures, such as P-frames and B-frames have many similar syntax elements. The picture layer (**1120**) includes a picture header (**1130**) followed by data for the macroblock layer. The picture header (**1130**) includes several picture-level elements that are processed by the decoder and used to decode the corresponding frame. Some of those elements are only present if their presence is signaled or implied by a sequence-level element or a preceding picture-level element.

For example, the picture header (**1130**) includes an intra transform DCT table (DCTDCTAB) element (**1137**). This field is present in P pictures and baseline I pictures (X8IF=0). DCTDCTAB (**1137**) is a 1-bit field that signals which of two sets of VLC tables is used to decode the transform DC coefficients in intra-coded blocks. If DCTDCTAB=0, then the low motion VLC tables (one for luminance DC, one for chrominance DC) are used. If DCTDCTAB=1 then the high motion VLC tables (one for luminance DC, one for chrominance DC) are used. The transform DC VLC tables are listed below.

The picture header (**1130**) includes a picture quantizer index (PQINDEX) element (**1131**). PQINDEX (**1131**) is a 5-bit field that signals the quantizer scale index for the entire frame. It is present in all picture types. If the implicit quantizer is used (signaled by sequence field QUANTIZER=00, see Table 2 above) then PQINDEX specifies both the picture quantizer scale (PQUANT) and the quantizer (3QP or 5QP deadzone) used for the frame. Table 3 shows how PQINDEX is translated to PQUANT and the quantizer for implicit mode.

TABLE 3

PQINDEX to PQUANT/Quantizer Deadzone Translation (Implicit Quantizer)		
PQINDEX	PQUANT	Quantizer Deadzone
0	NA	NA
1	1	3 QP
2	2	3 QP
3	3	3 QP
4	4	3 QP
5	5	3 QP
6	6	3 QP
7	7	3 QP
8	8	3 QP
9	6	5 QP
10	7	5 QP
11	8	5 QP
12	9	5 QP
13	10	5 QP
14	11	5 QP
15	12	5 QP
16	13	5 QP
17	14	5 QP
18	15	5 QP
19	16	5 QP
20	17	5 QP
21	18	5 QP
22	19	5 QP
23	20	5 QP
24	21	5 QP
25	22	5 QP
26	23	5 QP
27	24	5 QP
28	25	5 QP
29	27	5 QP
30	29	5 QP
31	31	5 QP

If the quantizer is signaled explicitly at the sequence or frame level (signaled by sequence field QUANTIZER=01, 10 or 11, see Table 2 above) then PQINDEX is translated to the picture quantizer step size PQUANT as indicated by Table 4.

TABLE 4

PQINDEX to PQUANT Translation (Explicit Quantizer)		
PQINDEX	PQUANT 3QP Deadzone	PQUANT 5QP Deadzone
0	NA	NA
1	1	1
2	2	1
3	3	1
4	4	2
5	5	3
6	6	4
7	7	5

TABLE 4-continued

PQINDEX to PQUANT Translation (Explicit Quantizer)		
PQINDEX	PQUANT 3QP Deadzone	PQUANT 5QP Deadzone
8	8	6
9	9	7
10	10	8
11	11	9
12	12	10
13	13	11
14	14	12
15	15	13
16	16	14
17	17	15
18	18	16
19	19	17
20	20	18
21	21	19
22	22	20
23	23	21
24	24	22
25	25	23
26	26	24
27	27	25
28	28	26
29	29	27
30	30	29
31	31	31

Alternatively, instead of the translation shown in Table 4, PQUANT is equal to PQINDEX for all values of PQINDEX from 1 through 31 when the quantizer is signaled explicitly at the sequence or frame level.

The picture header (**1130**) also includes a half QP step (HALFQP) element (**1134**) and picture quantizer type (PQUANTIZER) element (**1135**). HALFQP (**1034**) is a 1-bit field present if PQINDEX (**1033**) is less than or equal to 8. HALFQP (**1134**) allows the picture quantizer to be expressed in half step increments over the low PQUANT range. If HALFQP=1 then the picture quantizer step size is PQUANT+½. If HALFQP=0 then the picture quantizer step size is PQUANT. Therefore, if the 3QP deadzone quantizer is used then half step sizes are possible up to PQUANT=9 (i.e., PQUANT=1, 1.5, 2, 2.5 . . . 8.5, 9) and then only integer step sizes are allowable above PQUANT=9. For the 5QP deadzone quantizer, half step sizes are possible up to PQUANT=7 (i.e., 1, 1.5, 2, 2.5 . . . 6.5, 7).

PQUANTIZER (**1135**) is a 1-bit field present in all frame types if the sequence level field QUANTIZER=01 (see Table 2 above). In this case, the quantizer used for the frame is specified by PQUANTIZER. If PQUANTIZER=0 then the 5QP deadzone quantizer is used for the frame. If PQUANTIZER=1 then the 3QP deadzone quantizer is used.

The picture header (**1130**) further includes a macroblock quantization (VODPQUANT) field (**1136**). VODPQUANT (**1136**) may be used to adjust quantization step sizes for macroblocks (e.g., macroblocks at one or more edges of a frame, or on a per macroblock basis). For additional detail about VODPQUANT (**1136**), see U.S. patent application Ser. No. 10/623,195, filed Jul. 18, 2003.

FIG. **11**C is a macroblock-layer (**1140**) bitstream syntax diagram for progressive I-frames. The bitstream syntax for the macroblock layer of P-pictures and B-pictures contain many elements in common. Data for a macroblock consists of a macroblock header (**1150**) followed by block-layer data.

FIG. **11**D is an intra-coded block-layer (**1160**) bitstream syntax diagram. The block-layer data includes a transform DC coefficient (DCCOEF) element (**1161**), an escape transform DC coefficient (DCCOEFESC) element (**1162**), and a transform DC sign (DCSIGN) element (**1163**).

The DCCOEF (**1161**) field is only present in intra-coded blocks. This is a variable-length codeword that encodes a transform DC differential. The transform DC decoding process is described further below. One of two sets of code tables is used to encode the DC differentials (the table is signaled in the DCTDCTAB (**1137**) field in the picture header as described above). The DC VLC tables are also listed below.

The DCCOEFESC (**1162**) field is only present in intra-coded blocks and only if DCCOEF decodes to the escape code. The size of DCCOEFESC field can be 8, 9 or 10 bits depending on the quantization step size of the block.

DCSIGN (**1163**) is a 1-bit value that indicates the sign of the DC differential. If DCSIGN=0 then the DC differential is positive. If DCSIGN=1 then the DC differential is negative.

IV. Example Decoding and Dequantization of DC Coefficients for Intra Blocks

For typical intra-coded blocks, a decoder such as the decoder (**1000**) of FIG. **10** decodes coefficients, performs inverse quantization, and performs an inverse transform.

A. Decoding DC Differentials

The DC coefficient is coded differentially with respect to an already-decoded DC coefficient neighbor. This section describes the process used to decode the bitstream to obtain the DC differential.

FIG. **11**D shows the bitstream elements used to encode/decode the DC differential. DCCOEF is decoded using one of two sets of VLC tables (one for low motion and one for high motion). Each set of VLC tables includes a table for DC differentials for luminance blocks and a table for DC differentials for chrominance blocks. The table is specified by the DCTDCTAB (**1137**) field in the picture header. Based on the value of DCTDCTAB, one of the VLC tables listed below is used to decode DCCOEF. This will yield either:

1) zero, or
2) the absolute value of the DC differential, or
3) the escape code.

If DCCOEF decodes to zero, the value of the DC differential is also zero. Otherwise, further decoding is done to determine the value of the DC differential. If DCCOEF decodes to the escape code, the absolute value of the DC differential is encoded in the DCCOEFESC field. The size of the DCCOEFESC field is 8, 9 or 10 bits depending on the quantization step size of the block. The sign of the DC differential is obtained from the DCSIGN field. FIG. **12** lists pseudocode to illustrate the DC differential decoding process.

B. DC Differential VLC Tables

TABLE 5

Low-motion Luminance DC Differential VLC Table 1. Low-motion VLC Tables		
DC Differential	VLC Codeword	VLC Size
0	1	1
1	1	2
2	1	4
3	1	5
4	5	5
5	7	5
6	8	6
7	12	6
8	0	7
9	2	7

TABLE 5-continued

Low-motion Luminance DC Differential VLC Table 1. Low-motion VLC Tables		
DC Differential	VLC Codeword	VLC Size
10	18	7
11	26	7
12	3	8
13	7	8
14	39	8
15	55	8
16	5	9
17	76	9
18	108	9
19	109	9
20	8	10
21	25	10
22	155	10
23	27	10
24	154	10
25	19	11
26	52	11
27	53	11
28	97	12
29	72	13
30	196	13
31	74	13
32	198	13
33	199	13
34	146	14
35	395	14
36	147	14
37	387	14
38	386	14
39	150	14
40	151	14
41	384	14
42	788	15
43	789	15
44	1541	16
45	1540	16
46	1542	16
47	3086	17
48	197581	23
49	197577	23
50	197576	23
51	197578	23
52	197579	23
53	197580	23
54	197582	23
55	197583	23
56	197584	23
57	197585	23
58	197586	23
59	197587	23
60	197588	23
61	197589	23
62	197590	23
63	197591	23
64	197592	23
65	197593	23
66	197594	23
67	197595	23
68	197596	23
69	197597	23
70	197598	23
71	197599	23
72	197600	23
73	197601	23
74	197602	23
75	197603	23
76	197604	23
77	197605	23
78	197606	23
79	197607	23
80	197608	23
81	197609	23
82	197610	23
83	197611	23

TABLE 5-continued

Low-motion Luminance DC Differential VLC Table 1. Low-motion VLC Tables		
DC Differential	VLC Codeword	VLC Size
84	197612	23
85	197613	23
86	197614	23
87	197615	23
88	197616	23
89	197617	23
90	197618	23
91	197619	23
92	197620	23
93	197621	23
94	197622	23
95	197623	23
96	197624	23
97	197625	23
98	197626	23
99	197627	23
100	197628	23
101	197629	23
102	197630	23
103	197631	23
104	395136	24
105	395137	24
106	395138	24
107	395139	24
108	395140	24
109	395141	24
110	395142	24
111	395143	24
112	395144	24
113	395145	24
114	395146	24
115	395147	24
116	395148	24
117	395149	24
118	395150	24
ESCAPE	395151	24

TABLE 6

Low-motion Chroma DC Differential VLC Table		
DC Differential	VLC Codeword	VLC Size
0	0	2
1	1	2
2	5	3
3	9	4
4	13	4
5	17	5
6	29	5
7	31	5
8	33	6
9	49	6
10	56	6
11	51	6
12	57	6
13	61	6
14	97	7
15	121	7
16	128	8
17	200	8
18	202	8
19	240	8
20	129	8
21	192	8
22	201	8
23	263	9
24	262	9
25	406	9
26	387	9

TABLE 6-continued

Low-motion Chroma DC Differential VLC Table		
DC Differential	VLC Codeword	VLC Size
27	483	9
28	482	9
29	522	10
30	523	10
31	1545	11
32	1042	11
33	1043	11
34	1547	11
35	1041	11
36	1546	11
37	1631	11
38	1040	11
39	1629	11
40	1630	11
41	3256	12
42	3088	12
43	3257	12
44	6179	13
45	12357	14
46	24713	15
47	49424	16
48	3163208	22
49	3163209	22
50	3163210	22
51	3163211	22
52	3163212	22
53	3163213	22
54	3163214	22
55	3163215	22
56	3163216	22
57	3163217	22
58	3163218	22
59	3163219	22
60	3163220	22
61	3163221	22
62	3163222	22
63	3163223	22
64	3163224	22
65	3163225	22
66	3163226	22
67	3163227	22
68	3163228	22
69	3163229	22
70	3163230	22
71	3163231	22
72	3163232	22
73	3163233	22
74	3163234	22
75	3163235	22
76	3163236	22
77	3163237	22
78	3163238	22
79	3163239	22
80	3163240	22
81	3163241	22
82	3163242	22
83	3163243	22
84	3163244	22
85	3163245	22
86	3163246	22
87	3163247	22
88	3163248	22
89	3163249	22
90	3163250	22
91	3163251	22
92	3163252	22
93	3163253	22
94	3163254	22
95	3163255	22
96	3163256	22
97	3163257	22
98	3163258	22
99	3163259	22
100	3163260	22
101	3163261	22
102	3163262	22
103	3163263	22
104	6326400	23
105	6326401	23
106	6326402	23
107	6326403	23
108	6326404	23
109	6326405	23
110	6326406	23
111	6326407	23
112	6326408	23
113	6326409	23
114	6326410	23
115	6326411	23
116	6326412	23
117	6326413	23
118	6326414	23
ESCAPE	6326415	23

TABLE 7

High-motion Luminance DC Differential VLC Table 2. High-motion Tables		
DC Differential	VLC Codeword	VLC Size
0	2	2
1	3	2
2	3	3
3	2	4
4	5	4
5	1	5
6	3	5
7	8	5
8	0	6
9	5	6
10	13	6
11	15	6
12	19	6
13	8	7
14	24	7
15	28	7
16	36	7
17	4	8
18	6	8
19	18	8
20	50	8
21	59	8
22	74	8
23	75	8
24	11	9
25	38	9
26	39	9
27	102	9
28	116	9
29	117	9
30	20	10
31	28	10
32	31	10
33	29	10
34	43	11
35	61	11
36	413	11
37	415	11
38	84	12
39	825	12
40	824	12
41	829	12
42	171	13
43	241	13
44	1656	13

TABLE 7-continued

High-motion Luminance DC Differential VLC Table
2. High-motion Tables

DC Differential	VLC Codeword	VLC Size
45	242	13
46	480	14
47	481	14
48	340	14
49	3314	14
50	972	15
51	683	15
52	6631	15
53	974	15
54	6630	15
55	1364	16
56	1951	16
57	1365	16
58	3901	17
59	3895	17
60	3900	17
61	3893	17
62	7789	18
63	7784	18
64	15576	19
65	15571	19
66	15577	19
67	31140	20
68	996538	25
69	996532	25
70	996533	25
71	996534	25
72	996535	25
73	996536	25
74	996537	25
75	996539	25
76	996540	25
77	996541	25
78	996542	25
79	996543	25
80	1993024	26
81	1993025	26
82	1993026	26
83	1993027	26
84	1993028	26
85	1993029	26
86	1993030	26
87	1993031	26
88	1993032	26
89	1993033	26
90	1993034	26
91	1993035	26
92	1993036	26
93	1993037	26
94	1993038	26
95	1993039	26
96	1993040	26
97	1993041	26
98	1993042	26
99	1993043	26
100	1993044	26
101	1993045	26
102	1993046	26
103	1993047	26
104	1993048	26
105	1993049	26
106	1993050	26
107	1993051	26
108	1993052	26
109	1993053	26
110	1993054	26
111	1993055	26
112	1993056	26
113	1993057	26
114	1993058	26
115	1993059	26
116	1993060	26
117	1993061	26
118	1993062	26

TABLE 7-continued

High-motion Luminance DC Differential VLC Table
2. High-motion Tables

DC Differential	VLC Codeword	VLC Size
ESCAPE	1993063	26

TABLE 8

High-motion Chroma DC Differential VLC Table

DC Differential	VLC Codeword	VLC Size
0	0	2
1	1	2
2	4	3
3	7	3
4	11	4
5	13	4
6	21	5
7	40	6
8	48	6
9	50	6
10	82	7
11	98	7
12	102	7
13	166	8
14	198	8
15	207	8
16	335	9
17	398	9
18	412	9
19	669	10
20	826	10
21	1336	11
22	1596	11
23	1598	11
24	1599	11
25	1654	11
26	2675	12
27	3194	12
28	3311	12
29	5349	13
30	6621	13
31	10696	14
32	10697	14
33	25565	15
34	13240	14
35	13241	14
36	51126	16
37	25560	15
38	25567	15
39	51123	16
40	51124	16
41	51125	16
42	25566	15
43	51127	16
44	51128	16
45	51129	16
46	102245	17
47	204488	18
48	13087304	24
49	13087305	24
50	13087306	24
51	13087307	24
52	13087308	24
53	13087309	24
54	13087310	24
55	13087311	24
56	13087312	24
57	13087313	24
58	13087314	24
59	13087315	24
60	13087316	24
61	13087317	24

TABLE 8-continued

High-motion Chroma DC Differential VLC Table		
DC Differential	VLC Codeword	VLC Size
62	13087318	24
63	13087319	24
64	13087320	24
65	13087321	24
66	13087322	24
67	13087323	24
68	13087324	24
69	13087325	24
70	13087326	24
71	13087327	24
72	13087328	24
73	13087329	24
74	13087330	24
75	13087331	24
76	13087332	24
77	13087333	24
78	13087334	24
79	13087335	24
80	13087336	24
81	13087337	24
82	13087338	24
83	13087339	24
84	13087340	24
85	13087341	24
86	13087342	24
87	13087343	24
88	13087344	24
89	13087345	24
90	13087346	24
91	13087347	24
92	13087348	24
93	13087349	24
94	13087350	24
95	13087351	24
96	13087352	24
97	13087353	24
98	13087354	24
99	13087355	24
100	13087356	24
101	13087357	24
102	13087358	24
103	13087359	24
104	26174592	25
105	26174593	25
106	26174594	25
107	26174595	25
108	26174596	25
109	26174597	25
110	26174598	25
111	26174599	25
112	26174600	25
113	26174601	25
114	26174602	25
115	26174603	25
116	26174604	25
117	26174605	25
118	26174606	25
ESCAPE	26174607	25

C. Computing DC Predictors

The quantized DC value for a current block is obtained by adding a DC predictor to the DC differential. The DC predictor is obtained from one of the previously decoded adjacent blocks, which may be labeled candidate predictors A (from the block immediately above and to the left of the current block), B (from the block immediately above the current block), and C (from the block immediately to the left of the current block). The values for A, B and C are the quantized DC values for the respective adjacent blocks.

In some cases there are missing adjacent blocks. If the current block is in the first block row of the frame, there are no A or B (and possibly no C). If the current block is in the first block column in the frame, there are no A and C (and possibly no B) blocks. For these cases the DC predictor is set to:

$$DCPredictor=(1024+(DCStepSize>>1))/DCStepSize,$$

where DCStepSize is a value described below.

Otherwise, a prediction direction is formed based on the values of A, B and C, and either the B or C predictor is chosen. The prediction direction is calculated as follows. If the absolute value of (A−B) is less than or equal to the absolute value of (A−C), then the prediction is made from the left (C is the predictor). Otherwise, the prediction is made from the top (B is the predictor).

The quantized DC coefficient is then calculated by adding the DC differential and the DC predictor as follows:

$$DC\ Coeff\ Q=DCPredictor+DCDifferential$$

D. Inverse-Quantization for Baseline I-Frame Pictures

In each macroblock of a picture frame, the decoder decodes a DC coefficient and set of AC coefficients, which were each quantized at the encoder. These quantized transform coefficients are dequantized for a baseline I-Frame picture as described below.

1. DC Inverse-Quantization

The quantized DC coefficient (DC Coeff Q) is reconstructed by performing the following de-quantization operation:

$$DC\ Coefficient=DC\ Coeff\ Q*DCStepSize$$

The value of DCStepSize is based on the value of PQUANT as follows:

For PQUANT equal to 1 or 2:

$$DCStepSize=2*PQUANT$$

For PQUANT equal to 3 or 4:

$$DCStepSize=8$$

For PQUANT greater than or equal to 5:

$$DCStepSize=PQUANT/2+6$$

2. Inverse AC Coefficient Quantization

AC coefficients are separately decoded. Depending on whether the 3-QP or 5-QP deadzone quantizer is used, the non-zero quantized AC coefficients are inverse quantized according to the following formula:

dequant_coeff=quant_coeff*double_quant (if 3-QP deadzone quantizer), or

dequant_coeff=quant_coeff*double_quant+sign (quant_coeff)*quant_scale (if 5-QP deadzone quantizer)

where:

quant_coeff is the quantized coefficient

dequant_coeff is the inverse quantized coefficient

double_quant=2*PQUANT+HalfStep

quant_scale=PQUANT

PQUANT is encoded in the picture layer as described above. HalfStep is encoded in the picture layer as via the HALFQP element as described above.

V. Signaling for DC Coefficients with Small Quantization Step Sizes, Theory

In the implementation described in detail above, the range for differential DC coefficients becomes larger as the quantization step size becomes smaller. For example, the range for a quantization step size of 2 is twice as large as the range for a quantization step size of 4. Further, the range for quantization step size of 1 is four times the range for quantization step size of 4. A VLC table used to directly encode/decode the differential DC coefficient for such small step sizes would need to be very large and would impose excessive memory requirements in some cases (e.g., in small footprint devices). Further, as the lowest quantization step sizes are infrequently or rarely used in practical encoding scenarios, the cost of this additional memory requirement would not be justified.

The problem of excessively large VLC tables for very small quantization sizes is addressed in this implementation by designing the VLC tables to accommodate the range of differential DC coefficients when the quantization step size is 4. Then, for smaller quantization step sizes (e.g., 1 and 2), a multistage approach is used to signal the differential. DC coefficient. More specifically, at a quantization step size of 2, a standard VLC table is used to decode a base VLC for the differential DC coefficient. An additional 1-bit code is also decoded, and this is used to refine the value of the differential DC coefficient. At a quantization step size of 1, a standard VLC table again is used to decode a base VLC for the differential DC coefficient. An additional 2-bit code is also decoded and used to refine the value of the differential DC coefficient.

When the base VLC represents the escape code, a further FLC is used to signal the differential DC coefficient. The size of the FLC changes with the quantization step size. For example, the FLC is 8 bits for quantization steps sizes over 2, and 9 and 10 bits for quantization step sizes of 2 and 1, respectively. This reduces bit rate for the escape code FLCs for higher quantization step sizes.

Having described and illustrated the principles of our invention, it will be recognized that the various embodiments can be modified in arrangement and detail without departing from such principles. It should be understood that the programs, processes, or methods described herein are not related or limited to any particular type of computing environment, unless indicated otherwise. Various types of general purpose or specialized computing environments may be used with or perform operations in accordance with the teachings described herein. Elements of embodiments shown in software may be implemented in hardware and vice versa.

In view of the many possible embodiments to which the principles of our invention may be applied, we claim as our invention all such embodiments as may come within the scope and spirit of the following claims and equivalents thereto.

We claim:

1. A method of coding/decoding video, the method comprising, with a computing device that implements a video encoder and/or video decoder:

determining a quantization step size, wherein one or more syntax elements in a bit stream indicate the quantization step size;

processing a variable length code (VLC) for a DC differential for a DC coefficient using a VLC table that includes different VLC values associated with different values for the DC differential, wherein the VLC table further includes an escape code that indicates presence of a fixed length code (FLC) for the DC differential for the DC coefficient; and

when the VLC is the escape code:

using the quantization step size to determine a length of the FLC for the DC differential for the DC coefficient, wherein the length of the FLC varies depending on the quantization step size; and

processing the FLC for the DC differential for the DC coefficient.

2. The method of claim **1** further comprising, with the computing device, reconstructing the DC coefficient during decoding based at least in part on the FLC.

3. The method of claim **1** wherein the FLC indicates a value for the DC differential.

4. The method of claim **1** further comprising, during decoding, with the computing device:

computing a DC predictor;

reconstructing the DC differential based at least in part on the escape code and the FLC; and

combining the DC predictor and the DC differential.

5. The method of claim **1** further comprising, during encoding, with the computing device:

computing a DC predictor;

computing the DC differential based at least in part on the DC predictor and the DC coefficient; and

representing the DC differential with the escape code and the FLC.

6. The method of claim **1** wherein:

if the quantization step size is 1, the length of the FLC is 10;

if the quantization step size is 2, the length of the FLC is 9; and

otherwise, the quantization step size being greater than 2, the length of the FLC is 8.

7. A computer-implemented method of decoding video using a computing device that implements a video decoder, the method comprising, with the computing device that implements the video decoder:

determining a quantization step size for a block of a video picture based on one or more syntax elements in a bit stream;

receiving a variable length code (VLC) in the bit stream, wherein the VLC at least in part indicates a DC differential for a DC coefficient of the block of the video picture;

determining that the VLC indicates an escape code in a VLC table, the escape code indicating presence in the bit stream of a fixed length code (FLC) for the DC differential, the VLC table also including different VLC values associated with different values for DC differentials;

using the quantization step size to determine a length of the FLC for the DC differential in the bit stream, wherein the length of the FLC varies depending on the quantization step size;

receiving the FLC in the bit stream; and

decoding the FLC to determine a value for the DC differential; and

reconstructing the DC coefficient using the value for the DC differential, wherein the DC differential represents a difference between the DC coefficient and a DC predictor.

8. The method of claim **7** wherein:

if the quantization step size is 1, the length of the FLC is 10;

if the quantization step size is 2, the length of the FLC is 9; and

otherwise, the quantization step size being greater than 2, the length of the FLC is 8.

9. The method of claim **7** wherein the quantization step size is indicated at least in part by a picture-layer syntax element for the video picture and at least in part by a differential quantization syntax element that adjusts the quantization step size for a macroblock that includes the block.

10. The method of claim **7** wherein the VLC table is selected from among multiple sets of VLC tables.

11. The method of claim **10** wherein each of the multiple sets of VLC tables includes a table for DC differentials for luminance blocks and a table for DC differentials for chrominance blocks, wherein a first set of the multiple sets of VLC tables is adapted for low motion video, and wherein a second set of the multiple sets of VLC tables is adapted for high motion video.

12. The method of claim **7** further comprising, with the computing device that implements the video decoder, receiving a code in the bit stream that represents a sign value for the DC differential.

13. The method of claim **7** further comprising, for another block of the video picture:

determining a quantization step size for the other block of the video picture;

receiving another VLC in the bit stream, wherein the other VLC at least in part indicates a DC differential for a DC coefficient of the other block of the video picture;

determining that the other VLC does not indicate the escape code in the VLC table;

determining a base value for the DC differential for the DC coefficient of the other block using the other VLC;

receiving a code in the bit stream that indicates a refinement value;

multiplying the base value by a factor that varies depending on the quantization step size for the other block of the video picture; and

adding the refinement value to a result of the multiplying.

14. A computing device comprising a processor and memory, wherein the computing device implements a video decoder configured to perform operations comprising:

determining a quantization step size for a block of a video picture based on one or more syntax elements in a bit stream;

receiving a variable length code (VLC) in the bit stream, wherein the VLC at least in part indicates a DC differential for a DC coefficient of the block of the video picture;

determining that the VLC indicates an escape code in a VLC table, the escape code indicating presence in the bit stream of a fixed length code (FLC) for the DC differential, the VLC table also including different VLC values associated with different values for DC differentials;

using the quantization step size to determine a length of the FLC for the DC differential in the bit stream, wherein the length of the FLC varies depending on the quantization step size;

receiving the FLC in the bit stream;

decoding the FLC to determine a value for the DC differential; and

reconstructing the DC coefficient using the value for the DC differential, wherein the DC differential represents a difference between the DC coefficient and a DC predictor.

15. The computing device of claim **14** wherein:

if the quantization step size is 1, the length of the FLC is 10;

if the quantization step size is 2, the length of the FLC is 9; and

otherwise, the quantization step size being greater than 2, the length of the FLC is 8.

16. The computing device of claim **14** wherein the quantization step size is indicated at least in part by a picture-layer syntax element for the video picture and at least in part by a differential quantization syntax element that adjusts the quantization step size for a macroblock that includes the block.

17. The computing device of claim **14** wherein the VLC table is selected from among multiple sets of VLC tables.

18. The computing device of claim **17** wherein each of the multiple sets of VLC tables includes a table for DC differentials for luminance blocks and a table for DC differentials for chrominance blocks, wherein a first set of the multiple sets of VLC tables is adapted for low motion video, and wherein a second set of the multiple sets of VLC tables is adapted for high motion video.

19. The computing device of claim **14** wherein the operations further comprise receiving a code in the bit stream that represents a sign value for the DC differential.

20. The computing device of claim **14** wherein the operations further comprise, for another block of the video picture:

determining a quantization step size for the other block of the video picture;

receiving another VLC in the bit stream, wherein the other VLC at least in part indicates a DC differential for a DC coefficient of the other block of the video picture;

determining that the other VLC does not indicate the escape code in the VLC table;

determining a base value for the DC differential for the DC coefficient of the other block using the other VLC;

receiving a code in the bit stream that indicates a refinement value;

multiplying the base value by a factor that varies depending on the quantization step size for the other block of the video picture; and

adding the refinement value to a result of the multiplying.

21. One or more computer-readable memory devices storing computer-executable instructions for causing a computer system programmed thereby to perform decoding operations comprising:

determining a quantization step size for a block of a video picture based on one or more syntax elements in a bit stream;

receiving a variable length code (VLC) in the bit stream, wherein the VLC at least in part indicates a DC differential for a DC coefficient of the block of the video picture;

determining that the VLC indicates an escape code in a VLC table, the escape code indicating presence in the bit stream of a fixed length code (FLC) for the DC differential, the VLC table also including different VLC values associated with different values for DC differentials;

using the quantization step size to determine a length of the FLC for the DC differential in the bit stream, wherein the length of the FLC varies depending on the quantization step size;

receiving the FLC in the bit stream;

decoding the FLC to determine a value for the DC differential; and

reconstructing the DC coefficient using the value for the DC differential, wherein the DC differential represents a difference between the DC coefficient and a DC predictor.

22. The method of claim **1** further comprising, as part of rate control during encoding, with the computing device:

determining a level of a buffer that stores compressed video data; and

setting the quantization step size based at least in part on the level of the buffer.

23. The method of claim **22** wherein the rate control further comprises frame dropping and adaptive filtering.

24. The method of claim **22** further comprising, with the computing device:

channel coding the compressed video data for transmission over a network, wherein the channel coding applies error detection and correction data to the compressed video data.

25. The method of claim **7** further comprising:

buffering compressed video data for the bitstream; and performing error detection and error correction on the compressed video data.

26. The computing device of claim **14** further comprising a display, speaker, voice input device and communication connection, wherein the computing device further implements a buffer configured to store compressed video data received over the communication connection and a channel decoder configured to perform error detection and error correction on the buffered compressed video data.

27. The one or more computer-readable memory devices of claim **21** wherein the quantization step size is indicated at least in part by a picture-layer syntax element for the video picture and at least in part by a differential quantization syntax element that adjusts the quantization step size for a macroblock that includes the block.

28. The one or more computer-readable memory devices of claim **21** wherein the decoding operations further comprise:

receiving a code in the bit stream that represents a sign value for the DC differential.

29. The one or more computer-readable memory devices of claim **21** wherein the decoding operations further comprise:

buffering compressed video data for the bitstream; and

performing error detection and error correction on the compressed video data.

* * * * *